TESTING RADIO SETS

By

J. H. REYNER

B.Sc., A.C.G.I., D.I.C., A.M.I.E.E., M.Inst.R.E.
Consulting Radio Engineer
Technical Editor of *Amateur Wireless* and *Wireless Magazine*

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PREFACE

THE testing of radio sets covers a very wide field, for testing enters into every phase of modern radio technique. First of all, in the design stages, tests are required to ascertain the extent to which the designer's calculations have been carried out in practice. When he has completed a satisfactory model the whole organisation of routine testing comes into operation. Every component must be systematically tested, and, in addition, the assembled receiver must again be put through a form of test, the severity of which depends upon the thoroughness of the tests on the component parts.

The case of the home-constructed receiver is somewhat different, although the wise constructor puts rough tests on his components before building them into a complete assembly. Generally speaking, however, the home-constructed receiver is assembled and is then expected to work, for in the majority of cases the preliminary testing has already been done by the designer who made the original model and prepared the published design.

Both classes of set come together in the testing necessary after they have been put into commission. The best receivers break down at times and some systematic method of testing is necessary in order to discover in which department the trouble is located. In the case of the home-constructed receiver, this aspect of the question is perhaps of the greatest importance, for in many cases the receiver does not function in accordance with expectations. It may be due to faulty components or to incorrect assembly, but in the absence of any well-defined system of fault location a considerable amount of exasperation may be caused, not to mention disappointment.

So important is this latter aspect of the question that the earlier and larger portion of the book has been devoted to what I have termed "Fault Testing" on finished receivers. The second section of the book deals with "Laboratory Tests," which are of more particular interest to designers and works testers. An Appendix has been added dealing with testing of the component parts, and in this manner it is hoped that the very wide subject may be covered with a sufficient amount of detail.

I should like to acknowledge the assistance which I have received from my colleague, Mr. L. I. Leslie, for many valuable suggestions throughout the preparation of the book.

J. H. REYNER.

BOREHAM WOOD.
May, 1930.

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TESTING RADIO SETS

SECTION I

FAULT TESTING

CHAPTER I

Introduction

Fault location is one of the most important operations to be carried out in connection with a radio receiver. Without proper method it is also one of the most difficult, but if tackled in the right manner it need have no terrors, even for the uninitiated. The process is one of highly-trained inductive reasoning, for the most we can do is follow the laws of cause and effect. The properly constituted radio set receives energy on the aerial, amplifies it, alters the conditions and finally converts it into sound energy, the volume, fidelity and general character of which must conform to certain expectations. If this is not the case we have to find which particular link in the whole complex chain is not functioning at its correct efficiency.

The only way in which we can do this is by the employment of a system. If one is walking down a path in the dark and finds one's progress suddenly impeded, one instinctively puts out a hand to find the obstacle. According to the nature of the impedance—whether one has stubbed a toe, barked the shins or stopped a dastardly blow amidships, so one automatically looks for the obstacle in the appropriate region.

This is a natural exercise of the faculty of inductive reasoning. The brain automatically and instantaneously locates the point which has ceased to function correctly and sends the hand as a messenger to discover the cause. We have to use the same procedure in testing electrical machinery, for we are not able to see, except in very specialised cases, and we have to determine the cause of the trouble by finding whether each individual portion of the receiver reacts as it should do.

It is of interest to carry this simile somewhat further.

When I was quite young my mother taught me to hold out a hand in front when walking across a dark room, in order to encounter any obstacles in a somewhat less violent manner than might possibly be the case if I walked into them. This is a simple precaution, yet it has developed into a habit which has on many occasions, been of use. We can exercise the same precaution in the case of a radio set by making periodical examinations of the performance of the receiver in order to ascertain whether any obstacles are presenting themselves to the development of the fullest efficiency. To take a very elementary case, a periodical measurement of the voltage on the high tension battery indicates the state of discharge and enables one to order and have by a new battery before the old one suddenly runs down, or develops too high an internal resistance for satisfactory operation.

It is to be urged, therefore, that some of the more elementary of the tests which appear in the following pages should be applied as a matter of routine to sets which are already functioning in what appears to be a satisfactory manner. Gradual deterioration is difficult to detect aurally, but can be brought to light by a series of routine tests.

EQUIPMENT REQUIRED

Before discussing the actual methods to be followed, it would be as well to consider the equipment necessary. The first essentials are a voltmeter and a milliammeter, without the aid of which it is difficult, if not impossible, to carry out satisfactory testing. The voltmeter should be capable of measuring low-tension voltages up to 6 volts and high-tension voltages up to at least 150 volts. The milliammeter should preferably have a number of ranges, for one encounters receivers having currents ranging from 6 to 7 milliamperes up to 30 or 40 or even more in the case of power amplifiers. Probably the most satisfactory instrument is a combination meter capable of measuring all three quantities.

Such a meter as the Ferranti portable instrument, illustrated in Fig. 1, is a useful accessory. This instrument can be obtained in various ranges, one of the most useful being 7·5 and 150 volts and 30 milliamps. Another instrument of considerable value is the Onemeter marketed by Leslie Dixon & Co. This instrument is in the nature of a mass-production

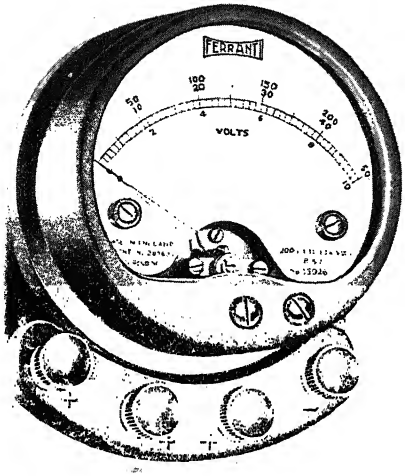

FIG. 1.—FERRANTI PORTABLE METER.

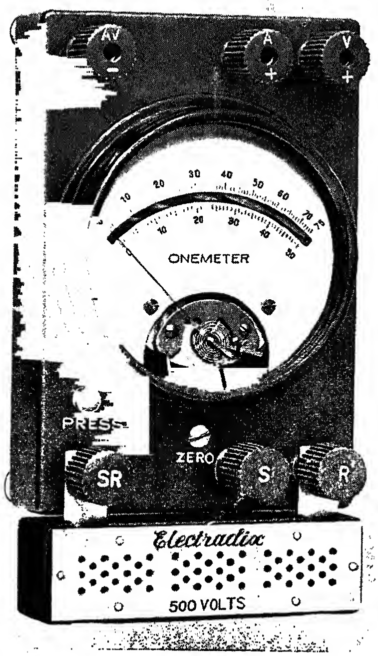

FIG. 2.—DIXON ONEMETER.

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precision instrument and is actually a milliammeter having a full scale deflection of 2 milliamps. By the use of suitable shunts and series-resistances, any desired range of current from 2 milliamperes upwards (full-scale) and 100 millivolts upwards may be measured.

It should perhaps be emphasised that the voltmeter and milliammeter should be of a thoroughly reliable moving coil type and should have a figure of merit of at least 200.[1] This is essential because a number of the tests which require to be made in practice depend upon the accurate determination of relatively small differences in the reading on the instrument, which must, therefore, be thoroughly reliable.

With this very simple equipment one can carry out the great majority of tests. Certain more specialised pieces of apparatus such as a valve emission tester, etc., will be described later on. One such piece of auxiliary apparatus, however, is practically a necessity. This is the wavemeter, an instrument which is used not so much for measuring wavelengths as for the provision of an artificial signal for testing purposes. A simple buzzer wavemeter is all that is required for most purposes. This consists of a tuned circuit calibrated in wavelength according to the setting on the dial. Coupled to the circuit is an energising circuit containing a buzzer, which is a small magnetic contact breaker. When the buzzer is connected to a battery the vibrating contact is set in motion, making and breaking the circuit several hundred times a second. The action is similar to the well-known trembler-bell, but much more rapid.

Each pulse of current in this energising circuit induces a

[1] The figure of merit of an instrument is a measure of the current taken by the movement in operation. This should be so small as to be negligible, but the production of a finely balanced movement requiring little power for its operation is an expensive matter.

A good meter will require 5mA to produce a full scale deflection. If used as a voltmeter it will then require a series resistance of 200 ohms for every volt full scale deflection. Thus if we introduce a series resistance of 2,000 ohms, we shall obtain a full scale reading with 10 volts, for $\frac{10}{2000} = .005$ amps or 5mA. We say that such an instrument has a figure of merit of 200 (ohms per volt).

The figure of merit may easily be determined for any meter by ascertaining the current in milliamps required for full scale deflection. This figure should be divided into 1,000. For example, the Onemeter referred to above gives a full scale deflection with 2mA. Hence its figure of merit is 500.

voltage into the tuned circuit and sets it oscillating, so that we have a series of trains of oscillations in the tuned circuit following one another at a musical frequency. This is exactly similar to the state of affairs with a spark transmitter, and if we tune our receiver to the wavemeter or vice versa, we shall hear a musical note just like a spark station.

We can use this for a source of artificial signals in testing different parts of a receiver or in measuring inductance or capacity, as will be seen later, or we can use it to determine the wavelength to which the receiver is tuned, by referring to the calibration.

Such instruments are easily made up, a suitable circuit being shown in Fig. 3. Alternatively, a convenient instrument made by Messrs. Wright & Weaire may be purchased complete and calibrated. This wavemeter, which is illustrated in Fig. 4, covers a range of 200–2,000 metres, and has the advantage of being more sharply tuned than usual owing to the use of an impact excitation circuit.

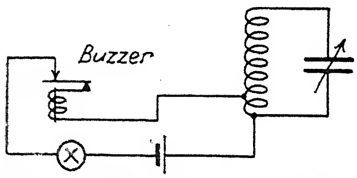

FIG. 3.—SIMPLE BUZZER WAVEMETER CIRCUIT.

For mains apparatus, more particularly operating from alternating current supply, certain other equipment is desirable. An A.C. voltmeter capable of reading up to 300 volts is useful for checking the supply voltage and the voltage on the secondary of the transformer where this is within the limits of the meter. A second range on the instrument is also desirable, capable of reading up to about 7·5 volts. This is in order to check the voltage on the filament circuits of the various valves, which may range from 0.8 volt to 7.5 volts according to the type of valve.[1]

A Ferranti rectifier voltmeter is a very convenient instrument and this may be obtained in ranges 2.5, 25 and 250 volts with a figure of merit of 200 or 1,000 as required. The lower value is satisfactory for ordinary work. The Onemeter, previously mentioned in connection with DC tests, can also be obtained in an AC form with suitable multipliers giving a range of 7·5 or 300 volts full-scale deflection.

[1] The 0·8 volt type of AC valve is being discontinued.

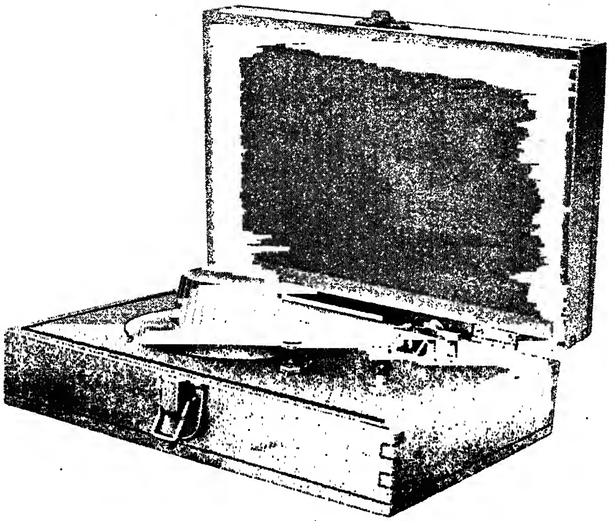

FIG. 4.—WEARITE WAVEMETER.

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One further instrument is desirable in connection with mains apparatus, and that is a voltmeter capable of reading up to 250 volts with a figure of merit of 1,000 ohms per volt. This, therefore, only takes 1 milliampere for full-scale deflection, so that no serious diminution of the voltage being measured results from a connection of the meter across the circuit. An instrument of this type is quite easily converted into a 500-volt meter of sufficient accuracy for testing purposes, by inserting a standard 250,000 ohm resistance in series. Correspondingly higher readings can be obtained if desired by the inclusion of further resistances.

This particular meter should be provided with a pair of test prods, consisting of insulating rods terminating in a metal point. This enables one to place the metal ends on live portions of the circuit without any danger of shock from personal contact with possible high voltages in the receiver. This precaution is very necessary, and even with the prods in use, the greatest care should be taken in making any test on the receiver while it is alive.

Such instruments as have already been described comprise the general testing equipment necessary for fault location. There is, however, one further instrument which will be found of considerable value, although it is by way of being a luxury instrument. This is an ohmmeter of some kind. There are occasions when a quick and easy method of measuring the resistance of a circuit is of use. As is described in the Appendix, a check on the resistance of any portion of the circuit may be obtained by use of the voltmeter already described, but an instrument which gives the actual resistance at a glance will often save time.

An ohmmeter is, of course, merely a milliammeter and battery all built into a suitable case whilst two terminals are provided for the connection of the external resistance to be measured; according to the value of this resistance so a greater or less deflection is obtained on the milliammeter needle. The scale is calibrated in ohms instead of in milliamps and suitable devices are incorporated in the circuit of the instrument itself to ensure that the calibration shall, as far as possible, be independent of the voltage of the battery within fairly wide limits.

An instrument of this class, which, while somewhat expensive, is very convenient, is the Avometer, which has three

resistance ranges from 0 to 10 ohms, 0 to 10,000 ohms and 0 to 1 megohm.

The same instrument has several voltage and current ranges so that it also acts as a voltmeter and milliammeter forming a very useful combination instrument. The instrument is illustrated in Fig. 5.

A smaller instrument reading from 10 to 10,000 ohms is also marketed by Messrs. A. F. Bulgin, Ltd.

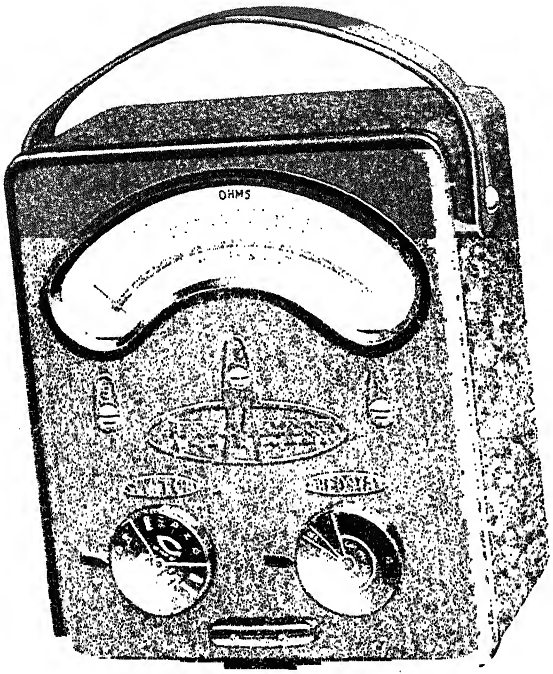

Fig. 5.—Avometer.

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CHAPTER II

General Testing Methods

Having described the instruments necessary for fault location, it is now necessary to discuss the methods to be adopted in general practice. The whole secret lies in the isolation of the particular portion of the receiver in which the fault has developed. This must be done in as expeditious a manner as possible and subsequently the actual faulty component in the particular section can be located by a narrowing down of the possible causes.

Generally speaking, therefore, our method is to ascertain systematically that each portion of the receiver is functioning correctly and this is usually best done by working from the low-frequency end of the receiver. That is to say, one starts with the output and gradually works up towards the input, taking each stage in turn. Various methods of carrying out detailed tests on each portion will be described in future chapters. The purpose of this chapter is to elaborate the particular system to be adopted.

Checking Anode Current

Now the first test to be made on any receiver is to ensure that the valves are working satisfactorily. For this purpose the connection from the negative terminal of the H.T. battery should be disconnected and a milliammeter inserted therein. The negative pole of a milliammeter is, of course, connected to the negative of the battery while the positive pole is connected to the negative terminal on the receiving set. The milliammeter should be shunted by a large condenser of 2μF during this test, because the introduction of a resistance in the common H.T. lead in this manner may set up a low-frequency oscillation. If this occurs, the milliamps reading obtained

from the different valves is quite likely to be upset and deceptive results may be obtained.

The range of the milliammeter must, of course, be chosen according to the set in use. Generally speaking, a range of about 30 milliamps will be satisfactory for receivers using up to four valves, but it is always advisable to note the valves in use and to estimate the probable total anode current in order to make sure that one will not seriously overload the meter. The table given herewith is a guide to the anode current taken by various classes of valve and will serve as a general basis of computation.

TABLE I

AVERAGE Static CURRENT TAKEN BY VARIOUS TYPES OF VALVE (MILLIAMPS)

NOTE.—*This table is to give an indication only. It is not intended for any accurate calculations.*

TYPE OF VALVE	H. T. VOLTAGE		
	100	150	200
With no bias—			
Screen Grid : Anode	2–4	3–5	—
Screen	1.0–1.5	1.0–1.5	—
R.C.	0.5–1.0	1.0–1.5	—
H.F.	1–2	2–3	—
With correct bias—			
L.F.	2-3	3-5	—
Power	4–6	6–9	10–15
Super Power . .	8–12	10–15	15–25
Pentode : Anode .	6–10	9–15	14–22
Screen .	1–3	2–5	3-7

Having inserted the milliammeter in this manner, the set should be switched on and the current noted. It should be particularly observed that all reaction controls and the like are set at the minimum position so that no portion of the circuit is in a state of oscillation. The anode current taken by an oscillating valve is quite different from that taken when the valve is static. It is nothing for a valve taking 1 milliamp normally, to take 30 milliamps when it is oscillating, and it will readily be appreciated that misleading results can easily arise from a cause of this nature. It may be that, even with the reaction control at zero, part of the circuit oscillates, in which case the offending circuit must be isolated and the trouble cured.

Assuming no such oscillation, however, the anode current should tally approximately with the figures computed from the knowledge of the valves in use. In any case, remove each valve in turn and note the decrease in the anode current. This will immediately give an indication as to whether the valves are functioning effectively.

In order to make this point quite clear it will be of interest to take an example. Let us consider that we have a 3-valve set having a screen-grid H.F. valve, followed by a detector (H.F. valve) transformer coupled to an ordinary power valve in the output stage. The H.T. voltage is 150, and therefore, by reference to our table, we can see that the total anode current should be about 16 milliamps. We now take out the power valve which should be responsible for about 9 milliamps. The milliammeter reading will, therefore, fall to 7 milliamps. The removal of the detector valve will cause a further drop of about 2 milliamps, leaving the remainder to be made up by the screen-grid valve.

Now if any of the three valves is faulty, the total current on switching on will not read the value of 16 milliamps. On removing each valve in turn, it will be found that one of the valves either causes no appreciable change in the reading or only causes a decrease very much less than it should do. This indicates that the valve has lost its emission. It is a very common form of fault and is more particularly found in the output stage although any of the valves in a receiver is liable to this gradual deterioration. If a valve is suspected it should be checked on a valve tester or replaced with a new valve.

For checking up suspected valves a special valve tester can be purchased or made up fairly readily and where any appreciable testing has to be done, such devices are of use. Special reference has been made to this subject in the Appendix dealing with Component Tests, wherein the technique of valve testing as it applies to the average user is explained in a fair amount of detail.

It is possible to find that all three valves in the receiver have deteriorated to an extent such that their emission is perhaps 50 per cent. of the normal value. The set then works but is lacking in both tone and power, and on replacing the valves with new ones the trouble will often be cured.

This systematic test of the valves therefore should be the first test to be placed on any receiver suspected of inadequate performance. It is indeed a good policy to check the emission of one's valves periodically even when the receiver is thought to be behaving in a satisfactory manner. One's ears become accustomed to a gradual falling off in performance and, therefore, some definite measurement at periodic intervals is of advantage.

Mains Apparatus

It should be pointed out at this juncture that the simple test just mentioned is not satisfactory where the receiver is operated from a mains unit. Mains units as a class have a poor regulation. That is to say, the voltage falls more or less rapidly as the current increases and vice-versa. Even if several tappings are taken on the eliminator, the voltages on these tappings are usually interdependent to a large extent. If, therefore, one suddenly removes the load from one tapping by removing a valve, the voltage on the other tappings will rise and the current taken by the remaining valves will increase beyond the normal value. Consequently, the drop in anode current due to the removal of the said valve will not be as great as it should be, and the results must be interpreted accordingly.

It is often preferable, in such circumstances, to use a battery for supplying the high tension voltage to the set, the mains unit being discarded for the time being. This avoids misleading results, the mains unit being brought into operation at a later stage when the fault in the receiver is located.

CONTINUITY OF CIRCUIT

Let us revert to the test on our imaginary receiver, and let us assume that the removal of the detector makes no difference to the reading on the milliammeter. Although a faulty valve will give this result, we must not jump to the conclusion that this is necessarily the cause of the trouble. A defect in the circuit such as a broken anode lead or too much grid bias, will give the same result. We must carry out further tests, therefore, to determine whether it is the valve or the circuit which is at fault.

The valve itself may be tested by one of the methods outlined in the Appendix, but the simplest procedure in actual routine testing is to put a fresh valve in the valve socket. Spare valves should always be available when carrying out tests on a receiver, and if the inclusion of a different valve, known to be good, in the particular socket does not give an increase in the milliammeter deflection, then the circuit is probably broken. For the purpose of this test, of course, it is not essential that the valve used shall be identical with the one just removed, but it should be of a similar type.

VOLTMETER TESTS

Assuming that the valves are O.K., we must look for a fault in the circuit. At this juncture it is advisable to adopt a somewhat different procedure. The tests so far have been made by the use of a milliammeter, measurements being made to see whether the current is of the expected order. We now proceed to measure the *voltage* at various parts of the circuit to see whether this again conforms to expectations. The milliammeter may, if desired, be removed from the circuit (as would be necessary if one were using a combination meter).

The voltmeter employed must have a range capable of measuring the full high-tension voltage applied to the receiver, and it is convenient to use the test prods referred to in Chapter I, as these often enable access to be obtained to somewhat cramped portions of the receiver. The method adopted is to check the voltage from the high-tension battery through each circuit in a progressive manner in order to see whether everything is in order.

In the case we have just been considering, we have assumed

that one valve is shown to be ineffective, the removal of this valve from its socket having no effect upon the anode current. In such a case we should attack this particular valve circuit first, but in the absence of any such definite indication, one would apply the test to each valve circuit in turn.

First of all we measure the voltage of the H.T. battery, on that particular tapping which is supplying the circuit in question. This, of course, should give us the correct reading within the limits to be expected;[1] otherwise the battery is faulty. We then measure the voltage on the terminals of the receiver, which should be the same, and continue to work backwards through the circuit. Assuming that the detector valve is the one which is at fault, we should pass through the transformer on to the anode of the valve itself. The voltage on the valve side of the transformer should be slightly less than the full amount owing to the small resistance drop on the transformer winding. If the valve, however, is passing no current as we have assumed, this will not be the case, and there will only be the small voltage drop due to the current taken by the meter itself, so that the voltage on the valve side of the transformer will either be the full H.T. voltage or nothing at all, in which latter case we have an indication that the transformer winding is broken.

Assuming the transformer to be satisfactory, we should continue the test, ultimately reaching the anode of the valve itself. This is measured actually on the pin of the valve, care being taken, of course, not to allow the lead to touch the filament pin at the same time, as otherwise there is a risk of the H.T. battery being short circuited through the filament and so damaging all the valves in the set.[2]

It is possible, for example, to find that the voltage is present at the anode terminal of the valve holder, but is not present on the valve itself. This indicates a break in the valve holder which should be removed and inspected.

A test such as this should have located the fault, but there is still a possibility that no definite fault has been found even after this time. If the voltage on the anode of the valve is

[1] A battery should not be allowed to run down below a voltage about 70 per cent. of the rated value. Otherwise the internal resistance will be unduly high and trouble will probably result.

[2] This risk is minimised if a flash lamp or other fuse is incorporated in the H.T. lead as described at the end of the chapter.

equal to the full H.T. voltage, indicating no voltage drop in the circuit and consequently no anode current, there are two possible sources of the trouble. The first of these is that the filament circuit of the valve is faulty so that the valve is receiving no filament current. This may readily be checked by connecting the voltmeter across the two filament pins, with the valve still in position.

If the filament circuit is found to be O.K. we are left with the grid circuit of the valve which may be broken or incorrectly biassed. Connect the grid terminal on the valve holder to L.T.—, and then again check the anode voltage. This should now be appreciably less than the full H.T. voltage, indicating that anode current is flowing, which shows that the grid circuit is at fault. The various tests which should be employed to locate trouble in the grid circuit are dealt with at length in the chapter on Tuning Tests.

This method of voltmeter testing is extremely valuable, and will very often give an indication of a fault. It is based on the principle that if a circuit is working correctly there will be a gradual drop in voltage from the most positive point (the H.T. battery) to the zero potential point (H.T.—). If the particular anode circuit contains a transformer or choke, the voltage drop will only be relatively small (the drop on a good transformer or choke is only between 10 and 20 volts), whereas if one is using resistance coupling, the voltage drop on such a component will, of course, be considerably more.

One either finds that the voltage drop is of the correct order, or else one of three things may happen. There may be no voltage drop (full voltage at every point) which indicates that the valve in question is not functioning. We may find no voltage at all which indicates a complete break in the circuit. Thirdly we may find an excessive voltage drop, particularly with resistance coupling, indicating that the valve in question is not receiving its fair share of anode voltage, and is, therefore, incapable of functioning properly. The voltmeter test, therefore, used with discrimination is one of the most valuable tests of all.

PROCESS OF ELIMINATION

We will assume, however, that the circuit is through as far as the anodes of the valves are concerned, and that each

valve takes its correct current and everything is, therefore, in order. Yet the fault, whatever it may be, remains. To discuss generally the methods to be adopted now becomes a matter of some difficulty, and the development of the principles in detail can only be carried out by considering various forms of test under particular headings. We can get some general idea of the method of procedure, however, by indicating the systematic principles which must be adopted.

Let us consider, for example, a simple two-valve set which just does not work. One's first operation, having tested the valves in the manner described, is to switch on the set. There should be a click in the loud speaker on switching on and again on switching off, which indicates that the loud speaker is functioning, probably satisfactorily. If there is any doubt this point should be verified.

We now desire to find out whether the low frequency stage is working satisfactorily. A simple and rapid way of testing this is to increase the reaction condenser on the set. A faint click or plop will usually be heard as the set goes into oscillation. The actual noise made depends upon the set itself, the better the set, the greater being the difficulty in observing the change from oscillating to non-oscillating condition.

Possibly the set is so constructed that too much reaction will cause a squeal to be set up. Either of these effects will serve to indicate whether the detector is feeding the low frequency portion satisfactorily or not. If no such effect is observed, one knows one of three things :

1. The H.T. voltages are not up to standard. This point should already have been checked.

2. The low frequency stage is not functioning satisfactorily.

3. The detector is not functioning satisfactorily.

Now we know from the simple valve tests which have already been made that both valves are satisfactory, and that the anode circuits are " through." That is to say, there is a definite connection throughout each of the anode circuits. Therefore, if the low frequency stage is not working, the transformer is defective or the connections to the low frequency valve are in some way faulty. Let us now endeavour to locate the fault more definitely.

L.F. Tests

Remove the detector valve from its socket and replace it again. A definite click should be heard on removing the valve, and a somewhat fainter click on re-inserting it. This is due to the breaking of the anode current passing through the transformer primary. If this click is not observed, the test should be made a little more definite by taking one of the connections off the transformer primary, and touching it on and off. A powerful click in the loud speaker should result, and if the click is either faint or non-existent, it indicates that the transformer is defective. It should be removed from its place and put through a test in accordance with the data given in the section on Component Testing.

It may be observed in passing that it is not absolutely definitely settled by this test that the transformer is faulty. All we know is that making or breaking the current through the primary winding of the transformer does not affect the anode circuit of the second valve. That is all we can say to be strictly correct. We can jump to the conclusion that the transformer is faulty by the following stages. The last valve is giving its correct anode current, therefore it is probable that the grid circuit of the valve is functioning satisfactorily; therefore we can assume that the transformer has broken down.

It should be emphasised, however, that this *is* only jumping to a conclusion. There are other points at which the circuit may have broken down. A valve will often give its correct anode current even if the grid is free. That is to say, even if the grid is not definitely connected to the filament through a suitable grid bias battery, but is actually connected to nothing at all. Therefore the fact that the last valve is giving its correct current does not prove that the circuit is correct.

It is quite within the bounds of possibility that the connection between the grid terminal on the valve holder and the grid socket itself is broken. This often happens with valve holders of the vibratory (so-called anti-microphonic) types. Or again, it is possible that a connection to the grid terminal of the valve holder, which may be a soldered joint, is bad, or perhaps a bad joint may occur in some other part of the grid circuit.

Detector Tests

If, however, the test on the transformer shows it to be in order, the grid circuit must be examined and tested for continuity right up to and including the valve pin, not forgetting the grid bias battery. Grid bias batteries have been known to develop internal breaks so that one assumes that a given voltage is being applied whereas in reality there is no circuit.

It should be added at this stage that in many cases indications of a broken grid circuit will be given by a howl or a rapid ticking, often known as "grid tick." This occurs when the circuit is such that the valve will fall in and out of oscillation very rapidly. It is not likely to happen in the general course of events with a low frequency valve, for if the low frequency stage is correctly designed there should be no tendency to self-oscillation. With sets of earlier design, however, a grid howl will often be set up if the grid circuit is disconnected. The absence of such howl, however, must not be taken as evidence that the grid circuit is correct. Where electric light is used a broken grid circuit usually picks up mains hum to an unusual degree and this will often provide a clue.

Tuning Tests

So far we have assumed that the fault has been proved to be in the low frequency stages. Let us assume, however, that we find that the L.F. stage is satisfactory. We then have to turn our attention to the detector. Now this may or may not be satisfactory according to the results obtained. If we have obtained a click or plop with the reaction condenser, then the detector valve is at any rate functioning in a somewhat satisfactory manner. If, on the other hand, we obtain nothing at all, but we know that the low frequency stage is correct because we get the necessary evidence by removing the detector valve completely, then we must examine the tuning circuit of the detector valve.

We know, to start off with, that the anode circuit of the detector is satisfactory, because we have obtained anode current from the detector valve. The first point is to examine the tuning circuit. Look at the coil and make sure that as far as can be seen there are no broken connections. See that the tuning condenser is correctly connected across the coil.

See that the connection between the tuning circuit and the valve are in accordance with proper practice.

At this stage it is desirable to produce the wavemeter and, adjusting the tuning circuit to some point within its range, place the wavemeter near to the set and endeavour to tune in the wavemeter to the set or vice versa. It may be necessary to place the wavemeter fairly close to the coil because the evidence so far is that the reaction is not functioning.

If we receive sharply tuned signals from the buzzer at the correct wavemeter reading, then we know that the tuning circuit is correct and that the connection to the valve is also correct. The fault, therefore, lies in the reaction circuit, and this should be examined in order to ensure that the coil is correctly connected (the right way round), and that the reaction condenser is functioning properly. If no obvious fault is found, then a continuity test should be made through the reaction coil until the fault is discovered and the reaction circuit is made to produce the necessary oscillation. When this is done, the signal strength on the buzzer should be capable of being increased quite considerably by the reaction condenser right up to the point where oscillation commences; this is then a satisfactory indication that the circuit is working more or less correctly. It then only remains to remove the buzzer wavemeter, connect up the aerial and earth and receive signals. If signals are not received, then the fault has now been definitely located to the aerial and earth system, and a little examination of these points should rapidly result in a location of the difficulty.

If, on the other hand, the buzzer wavemeter signals cannot be picked up on the circuit, whether the reaction is working or not, then it indicates a fault in the tuning circuit or in the connection between this and the valve. The first thing to do is to test the continuity of the tuning coil. The variable condenser should be tested to make sure that it is not short-circuited. This is done by removing the coil or disconnecting it momentarily, and then making a continuity test across the condenser. This test should give an indication of an open circuit, failing which the condenser is short-circuited. If the tuning circuit proves satisfactory, then one must examine the connections from the said circuit to the valve, as there are various possibilities of error. (For all these tests see Appendix.)

Apart from the possibility of bad connections, there is, in the case of the grid detector, the possibility of a broken grid condenser. The only satisfactory procedure in this case is to replace it with another condenser known to be good.

Still another possibility is that the circuit tunes quite well, but in an obviously incorrect manner. Tuning may be found to be all at the top or all at the bottom of the dial. In this case, the coil is obviously either incorrect in itself or incorrectly connected. These various tests indicate the vulnerable point in the circuit, and by approaching each one systematically, applying tests and learning from the result of those tests which particular portion of the circuit is wrong, we can finally track the fault down to its lair.

KNOWLEDGE OF CIRCUIT

This hypothetical examination of a two-valve set has been discussed with a fair amount of detail in order to disclose the particular methods which must be adopted. It must be emphasised again that system is the only method to be adopted. One must, first of all, divide the receiver into its separate constituents, such as the detector circuit and L.F. circuit. Rough tests are made to determine in which of these portions the fault lies. Each circuit must then be sub-divided into smaller portions and more exacting tests carried out in order to determine where the particular trouble is likely to lie. Having isolated one particular portion of the circuit, the final most careful tests must be made on that portion to discover the fault.

Two points will stand out from the analysis already made. Firstly it will be clear that the tests themselves grow more stringent as we progress. Secondly, although a form of circuit was mentioned at the beginning of the discussion to help the reader, little reference has been made to the circuit throughout the tests. This shows that with a proper system it is not necessary to know the circuit in detail, provided one has some rough idea as to what is to be expected. This cannot be taken as an invariable rule, but it may be accepted that the method of testing is largely independent of the circuit.

It is, of course, a distinct advantage to know the type of circuit with which one is dealing. One may experience puzzling results from tests which can often only be understood

by a knowledge of the circuit itself, but these cases are usually in the minority. One should endeavour to obtain a copy of the circuit to which the receiver has been wired. If this cannot be done, then in the event of any serious difficulty, a circuit diagram should be traced out partly by inspection of the wiring and partly by the aid of a continuity tester. Such a continuity tester should be of the ohmmeter class. That is to say, it should be capable of measuring resistances, and discriminating for example, between a direct connection and a connection through a coil.

One should be able to measure high resistances with a certain degree of approximation in order to determine which are grid leaks and which are anode resistances, and details as to how this may be done are given in the Appendix. Gener-

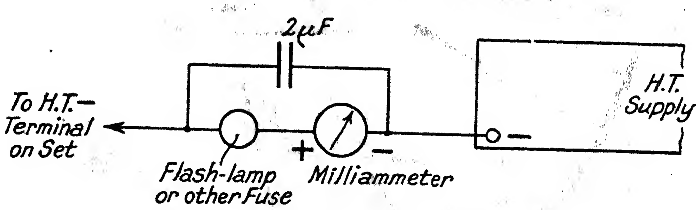

FIG. 6.—ILLUSTRATING USE OF FUSE IN H.T. CIRCUIT.

ally speaking, however, one can locate a fault without a definite knowledge of the circuit other than some idea of the principles involved. Having narrowed the fault down to a certain limited section of the receiver, one may then make a detailed circuit diagram of the particular portion and then devise scientific tests on each of the various components in order to ascertain which is faulty.

This chapter, therefore, gives the general methods to be adopted in fault location. The following chapters in the book will deal with each of the various aspects more exhaustively and discuss tests to be applied on more complex receivers than that just described in order to eliminate various portions one at a time and leave the faulty component exposed.

A PRECAUTION

One final tip may be given in connection with testing of receivers generally. A small flash lamp bulb, or similar fuse,

should be included in the H.T.-lead with the milliammeter. This will save damage to the valves or the meter. The bulb should be of the specially sensitive type, taking 60 milliamps only at 2 volts. This will fuse at about 100 milliamps. The condenser across the meter must also shunt this fuse, as this has quite a high resistance and trouble may arise if it is not shunted with a condenser (see Fig. 6).

CHAPTER III

Low Frequency Tests

Having discussed general methods of testing it now remains to investigate the various portions of the receiver in greater detail. This chapter is concerned with the various tests which may be necessary upon low frequency apparatus. The low frequency portion of the receiver commences immediately after the detector stage, and may consist of any number of stages, although in ordinary practice one or two stages are sufficient. The input voltage at which the modern detector valve functions is such that two stages of amplification following will usually give adequate loud speaker strength, even for large power outputs. In gramophone reception the detector valve is used as the first low frequency valve, thus obtaining a three-valve arrangement, and amplifiers having a larger number of stages than this are only occasionally encountered.

Now the faults which develop in low frequency amplifiers may be as under:

1. Amplifier refuses to function at all.
2. Amplifier operates with little power.
3. Amplifier operates with bad quality.
4. Amplifier howls or whistles continuously.

These various cases will be dealt with *seriatim*.

AMPLIFIER REFUSES TO FUNCTION

Where the low frequency amplifier does not work at all the location of the difficulty is fairly simple. The methods which must be adopted are those discussed in the last chapter. Some progressive indication of the soundness of the circuit must be obtained working from the back of the set towards the front. In this connection a device enabling low frequency voltages to be set up in different parts of the circuit will be

found to be of use. A gramophone pick up is such a device and it may be employed to a considerable extent in amplifier testing. Failing this, signals received on the radio portion of the receiver may be utilised, always assuming that this is in order.

The radio portion may be checked by placing a pair of telephones in the anode circuit in order to see whether signals are received at this stage. Assuming that this is so, then the fault lies in the amplifier, where it can be located by a process of elimination.

For example, we may connect the telephones in the anode circuit of the first L.F. valve. If there are no signals here, then this stage is at fault. If a good signal is obtained at this point, then the telephones should be transferred to the anode of the second L.F. valve and so on.

This method is an alternative to that suggested in the last chapter. Still a third method is the progressive examination of the circuit with a gramophone pick-up, as suggested in the next section of the present chapter. The application of system enables the faulty stage to be discovered with little difficulty, after which the location of the actual faulty component may be carried out with the aid of voltmeter tests, as described in the last chapter.

Broken Grid

In some cases a howl or hum may be experienced on switching on. This may be due to self-oscillation in the amplifier which is considered at the end of this chapter, or it may arise from a broken grid circuit. This possibility was referred to in the previous chapter.

Particularly if the detector grid circuit is broken, is this trouble likely to occur. Any external source of interference such as hum from electric light mains is picked up to an unusually great extent where the detector grid is free, and this often gives a clue to the position of the fault.

Failing this, the various valves should be removed in turn, to find which stage has introduced the trouble. If on further investigation the grid circuit of this stage is shown to be broken, the trouble may be remedied at once, while if such is not the case the difficulty arises from self-oscillation, and the remedies dealt with at the end of this chapter must be applied.

Another symptom of a broken grid circuit is a peculiar choked or throttled sound. The signal is obviously trying to get through, but is unable to do so due to a complete break in a vital part of the circuit.

AMPLIFIER FUNCTIONS WITH REDUCED EFFICIENCY

This is a much more difficult type of fault to locate. The class of fault where the circuit behaves, but is not up to its full standard, always requires more care and attention than the definite breakdown.

The first test, as already mentioned, should be made on the valves, to make sure that they are functioning correctly. In a case such as this the simple milliampere test is hardly sufficient; the valves should be inserted in a valve tester such as is described in the Appendix, or alternatively new valves should be used in place of the existing ones.

If no cure is effected, the next step is to replace each component in the circuit in turn, or failing this, to remove the particular component and dispense with it for the time being. For example, an amplifier has been known to become a mere shadow of its true self by the use of a bad output transformer; on removing the transformer altogether, connecting the loud speaker directly in the anode circuit, the results were greatly improved. Even an incorrectly matched transformer may result in a considerable drop in the strength.

Let us, as a matter of interest, analyse the circuit shown in Fig. 7. This is a well-known type of amplifier, comprising a resistance and transformer stage. In the output circuit of the last valve we have an output transformer. We will assume that this circuit functions, but in a poor manner.

First of all the valves would be checked as already described. Next the voltmeter test would be applied to the circuit in the manner referred to in the last chapter. The H.T. voltage would be checked on each circuit from the actual H.T. point on the battery or mains unit through the circuit to the valve itself. This test would dispose of any possibility that one or more of the valves was receiving less than its fair voltage, or that for some reason one valve was receiving considerably more than its due amount. Such a case must be

regarded with equal suspicion, for it may indicate that the particular valve is over-biassed, in which case it cannot function correctly. Incidentally, the grid bias on each stage should be checked to make sure that it is of the correct value, and that it is the right way round. A reversed grid bias battery has been known to cause considerable perplexity.

Valves and voltages being satisfactory, we must then proceed to examine the components themselves. This again we do in a systematic manner, working through the set from one end to the other. Let us proceed from the output stage backwards. The first step will be to disconnect the output transformer and to join up the loud speaker directly in the

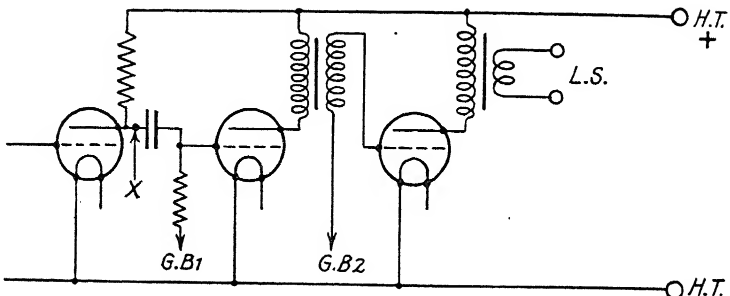

Fig. 7.—Typical Three-Valve Amplifier.

anode circuit of the last valve. This, of course, assumes that the loud speaker is of the high resistance type. If not, an alternative speaker should be obtained temporarily. The strength of reproduction obtained with this altered connection should be much the same as before if the output transformer is functioning satisfactorily.

Weak Signal

Incidentally testing of this nature should always be carried out on a weak signal. For one thing the ear is more sensitive to changes in strength when the intensity is small. It is impossible to obtain any accurate gauge as to the effect of an alteration if the general level of sound intensity is large.

Under conditions such as this, the matching of the loud speaker to the valve is of less importance since the question of overloading does not enter into the calculations and, there-

fore, one would find the strength much the same whether an output transformer or choke is used, or whether the loud speaker was directly in the anode circuit of the last valve. A serious reduction of strength on replacing the transformer indicates that this component is either faulty or incorrectly matched. Put it on one side and deal with it in the manner discussed in the Appendix.

We will assume, however, that this portion of the circuit is correct. Working one stage farther back, we come to the transformer, assuming that the valve is correct which we have already checked. Now transformers have been known to be connected the wrong way round. The first thing, therefore, is to examine the connections, and preferably to test the transformer itself (see Appendix). This may be done *in situ* if all batteries are disconnected. Failing any definite indication here, the next step is to eliminate the transformer. The simplest method of doing this is to replace the transformer itself with another component of similar character and to see whether the results are still the same as before.

One Step Farther

It is a good plan at this stage to connect a gramophone pick-up across the primary of the transformer. The strength of the signal will be weak, probably just audible, but the volume of sound should be noted and mentally observed.

The next procedure is to go one stage farther back, and apply the pick-up to the grid of the second valve. Any other leads going to the grid terminal of the second valve holder should be removed for the time being, the pick-up being connected between the grid terminal and the grid bias. It is sufficient for a rapid test merely to remove the principal components likely to have any influence. For example, one would remove the grid leak and anode resistance in front of the second valve, in the case just considered.

Now the response obtained from the pick-up or other testing device should be considerably enhanced by the introduction of this further link in the chain. Indeed a pick-up applied directly across the grid of the second valve followed by a transformer-coupled amplifier should give good loud speaker strength of the circuit if functioning correctly. If this is not found to be the case, then the fault can be assumed

to be in the valve holder or the valve, and should be fairly easily located.

If the step-up *is* present, then it is necessary to proceed one stage farther back again. The lead of the pick-up which formerly went to the grid of the valve, should now be connected to point X in the diagram, the grid leak being reinserted into its clip. The previous valve should be removed (the anode resistance has already been taken out) in order to isolate the circuit and the signal strength should now be exactly the same. That is to say, the inter-position of the grid condenser and the grid leak, should have no appreciable effect upon the signal strength.

If there is a drop in strength, one would suspect the coupling condenser, which may either be too small in value or perhaps broken internally.

It is not an uncommon thing to find a fixed condenser, particularly if of cheap manufacture, to have a broken connection inside. The customary test which one puts on a condenser is that of continuity, and of course the condenser will show an infinite resistance whether it is satisfactory or whether it has a break. To check this point connect a good condenser in parallel with the existing one. If the latter is O.K., no variation in strength will result; but if it is defective a marked difference will be observed.

The next step is now to come right back to the beginning of the amplifier, re-inserting the anode resistance and the first valve. Once again, a distinct step-up in volume should be obtained. If it is not, then either the anode resistance is faulty or the coupling condenser, while being satisfactory as a condenser, has some sort of leak across it, so that the high tension voltage which is now applied across the condenser owing to the re-insertion of the anode resistance is polarising the grid of the second valve.

Measure the voltage across the grid leak of the second valve with a high resistance voltmeter. There should be no voltage drop whatever upon the grid leak if the circuit is working correctly, but if the coupling condenser is leaking, a voltage will be developed which can be detected on the meter.

Failing any of these points, the first valve holder itself should be suspected, and if found faulty, replaced. By goirg over the set inch by inch in this manner, working from the

back towards the front, the fault must almost inevitably be located. Should any difficulty still persist after these steps have been taken, then the only alternative is to replace each component in turn, together with the wiring. The tests already made should indicate whether the component itself was faulty; the wiring, however, has not been sufficiently tested and new leads should be run from the appropriate points to the terminals of the new components in order to make sure that the wiring itself is satisfactory.

Checking Grid Bias

At the beginning of this chapter the necessity for checking the grid bias was referred to. It will be as well to discuss this matter in more detail. The voltages should be checked at the bias points themselves, and also on the valves. A little care is required in interpreting the results as will be seen. The high resistance voltmeter which is customarily used for eliminator tests is best employed for this purpose. This instrument will have a resistance of 250,000 ohms, and will not cause a serious drain on the circuit across which it is connected. If, for example, one wishes to check the grid bias of the two stages of the amplifier in question, the first check would be across the grid bias battery in the last stage. This would be say 9 volts. The next tests would be between the grid and filament. This again should be 9 volts, because the resistance of the secondary of the transformer is small compared with that of the voltmeter and, therefore, no appreciable voltage drop will result and the valve itself should receive the full 9 volts bias. Should this not be found to be the case, then the secondary of the transformer or the wiring between the transformer and the remainder of the set is faulty.

When we deal with the first valve we have a slightly different state of affairs because there will be a voltage drop on the grid leak. Normally, the grid circuit takes no current and, therefore, the grid leak will not cause any voltage drop. The connection of a voltmeter across grid and filament, however, will take a current and owing to the low resistance of the voltmeter (for even 250,000 ohms is small compared with 1 or 2 megohms) most of the voltage will be dropped on the resistance itself. One can, therefore, adopt two methods. Firstly, one can short-circuit the grid leak by removing the

grid leak and putting a short-circuiting bar in its place. This will, of course, check the wiring, for the voltage between grid and filament should then be exactly the same as the voltage across the grid bias battery. This has the disadvantage, however, that it does not test the leak.

The alternative method is to work out the amount of voltage which one might expect across the voltmeter itself. In order to obtain a satisfactory reading it may be necessary to increase the grid bias on this particular valve for the purposes of test. For example, suppose one has a 1 megohm leak. Then if the meter resistance is 250,000 ohms, $\frac{1}{5}$th of the total voltage will be developed across the meter, the remaining $\frac{4}{5}$ths being developed across the grid leak. The equivalent circuit is as shown in Fig. 8, from which this reasoning will be quite clear.

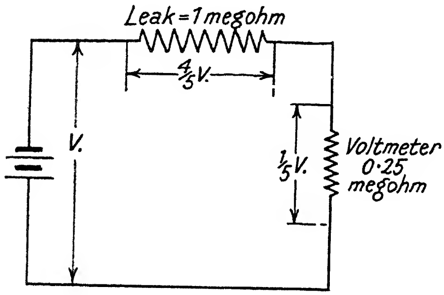

Fig. 8.—The Current taken by the Voltmeter causes a large Drop in Voltage on the Grid Leak.

Let us, therefore, increase our voltage to 9. Then the meter should give an indication of 1.8 volts, i.e. approximately 2 volts, if the grid leak is correct. This is perhaps difficult to measure on an instrument reading 250 volts full scale, but if there is any doubt, the voltage can be increased temporarily to 20 or 30 volts, in which case a reading of 5 or 6 volts across the meter will be obtained, and this will immediately show whether the grid leak is of its correct value or not.

So much for the rather awkward case where the circuit does not develop its full efficiency. Only one example has been considered, but the method is what matters, and this should be quite clear from the detailed manner in which the examination of the hypothetical circuit has been conducted.

BAD QUALITY

Failure to obtain true quality from the amplifier may be due to a variety of causes. One must discriminate, of course,

between an amplifier which is known to be of correct and good design, and one which has been made up, perhaps, without adequate knowledge. Manufactured sets must be assumed to be satisfactory, at any rate during the preliminary tests.

The first thing is to test the quality on a signal of medium strength. This removes, for the time being, the danger of overloading, or at any rate should do so if the design of the amplifier is satisfactory. If the quality still remains bad, then one of two things is happening. Either the quality is being distorted by an extraneous influence or the components are quite incorrect in their values. One of the principal sources of extraneous trouble is high frequency energy obtained from the earlier stages of the receiver. The presence of these high frequency currents usually gives rise either to a whistle in the low frequency stages—a point which will be referred to in the next section—or to a thin reedy quality.

Distortion Due to H.F. Currents

The first step, therefore, is to remove the high frequency valves, if any, and to disconnect, as far as possible, all the tuning circuits from the input to the amplifier. Where one is dealing with a made-up set, this of course means the disconnection of the set, up to and including the detector stage. A convenient way of achieving this without actually disconnecting any wires is to use a gramophone adapter, which is a simple valve holder having sockets on one side and pins on the other. This fits into the standard valve socket while the valve itself is placed in the sockets on the adaptor. The filament and anode pins are connected straight through but the grid pin is disconnected and is brought out to a terminal on the side of the adaptor. One is, therefore, able to introduce voltage across the grid and filament quite separately from the high frequency portion of the receiver, and this will eliminate the high frequency input. The H.F. valves should be removed from their sockets.

A gramophone pick-up should be connected to the adaptor and the quality should now be found to be satisfactory if the distortion has been due to the presence of high frequency energy as suspected. It should perhaps be remarked in passing that a high frequency current can sometimes arise apparently

from nowhere. A case in point is an amplifier in which there were three straightforward L.F. valves having no pretence at high frequency amplification. No tuning circuit came anywhere within feet of the amplifier and yet high frequency currents were found to exist. Therefore the removal of the tuning and high frequency amplifying circuits from the front of the amplifier does not in itself constitute an infallible cure for high frequency currents. Some trace of the distortion may still remain, and if so, it is necessary to adopt some of the various possible devices for keeping the high frequency out of the more vital portions of the L.F. amplifier.

H.F. Chokes and Stoppers

Assuming that high frequency is found to be the cause of the distortion, we must then arrange to by-pass the energy from the low frequency portion of the amplifier as effectively as possible. A good high frequency choke in the anode circuit of the first valve is an essential. Too many of the chokes which are found in modern equipment are not of a sufficiently high standard to act as an effective barrier. An effective choke should have an inductance of 200,000 μH with a self capacity of 3 or 4 $\mu\mu$F only. Coupled with the use of a high frequency choke, the use of a by-pass condenser is a *sine-qua-non.* It is of no use whatever to endeavour to choke back high frequency or any other form of energy unless an alternative path is provided for the energy which is to be withheld. Therefore, on the live or high frequency side of the choke one must connect a by-pass condenser of any value up to .0003μF, down to L.T-, as shown in Fig. 9. In some cases the value may even be increased, but when this is done, there is a tendency to cut off the top notes of the low frequency reproduction, and in general, a value of up to ·0003μF will be found to be sufficient.

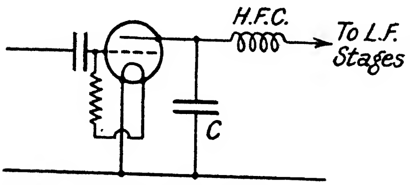

Fig. 9.—The H.F. Choke must have a By-pass on the Live Side, as shown at C.

If the circuit is not provided with a by-pass condenser, therefore, the omission should be repaired. If a condenser

is present, make sure that the choke is a good one before proceeding farther.

Further obstacles in the path of high frequency currents may be placed by inserting stopper resistances in the grid leads. These resistances should have a value of approximately 100,000 to 250,000 ohms. They operate by reason of the capacity between grid and filament of the valve, and the relative reactance of this capacity at radio frequencies and low frequencies.

The equivalent circuit is shown in Fig. 10, from which it will be seen that we have virtually a resistance in series with a capacity, and it is the voltage across the capacity which is actually applied to the valve. At low frequencies the reactance of the capacity is very large and consequently the greater

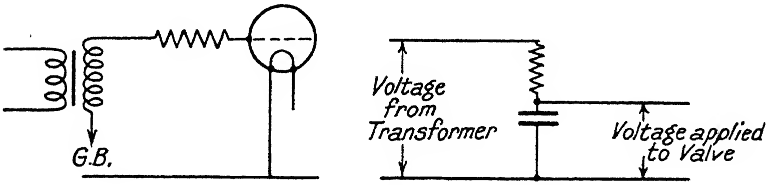

FIG. 10.—ILLUSTRATING ACTION OF GRID STOPPER.

part of the voltage is developed across this capacity. The resistance, therefore, has no effect in cutting down the signal strength. At high frequencies on the other hand, the reactance of the capacity is quite small compared with the resistance, and therefore most of the high frequency energy is lost in the resistance; only a small portion thereof is actually applied to the valve.

A third method of by-passing the energy is to connect a small condenser across the secondary of the transformer or from the anode of the second valve to L.T-. These condensers must again be small in order to avoid by-passing the top notes in the reproduction, and generally speaking, methods such as this are not found necessary if the remedies already outlined have been put into practice. A practice which is often necessary in portable sets is the connection of a condenser of $\cdot001\mu F$ to $\cdot002\mu F$ across the loud speaker itself, or alternatively, across from the live side of the loud speaker to L.T-. This serves to by-pass the high frequency energy which does reach

the loud speaker stage which, in a portable set, usually gets there by direct induction and not by passing right through the amplifier so that a heavy by-pass of this nature is necessary in order to minimise the defect. Needless to say, such a heavy by-pass as this has an adverse effect on the quality, but the results are more pleasant than the thin high-pitched tone which results when H.F. currents are present.

Saturation. Parallel Feed

If investigations prove, however, that distortion is not arising from the presence of high frequency currents, and if the quality is still bad on a weak signal, then one must look for some seriously incorrect values of the components. In a transformer-coupled amplifier saturation of the iron circuit may be responsible for the trouble. The presence of the steady current in the anode circuit reduces the inductance of the primary winding of the transformer to a greater or less extent. If a transformer with an inadequate iron circuit is used after the valve which passes a fairly heavy anode current, then the inductance of the transformer primary may be reduced to a mere fraction of its normal value. The result of this will be that the reproduction of the transformer is quite inadequate for the circumstances and the quality will sound thin and reedy.

In order to verify whether this is happening, it is necessary either to replace the transformer with another transformer known to be of good quality and capable of standing up to the job, or to arrange a choke or parallel feed to the transformer in question. This is done by feeding the high tension to the anode of the valve through a high inductance choke. The low frequency currents are by-passed through a condenser on to the transformer as shown in Fig. 11. This may be hooked up quite external to the set, and if the quality improves then the transformer is not suitable for use directly in the anode circuit and must either be replaced or provided with some form of parallel feed.

On the subject of parallel feed, it should be pointed out that the choke itself should have a high inductance of between 50 and 100 henries for preference. This is, of course, at the particular anode current which the choke is carrying. Undoubtedly the most satisfactory method is to use a constant

inductance choke in this position. These chokes are designed with a small air gap in the magnetic circuit so proportioned that the inductance remains almost constant over the full working range of current. One such choke is illustrated in Fig. 12, this being made by Messrs. Wright & Weaire.

Parallel feeding may be obtained by the use of a resistance instead of a choke, but this requires a certain amount of careful proportioning, for if the resistance is too high, the voltage drop is excessive and the voltage on the valve itself is reduced to too low a value. On the other hand, if the resistance is too low, it exercises a shunting effect across the primary of the transformer, and so defeats its own object, which is to maintain a high impedance in the anode circuit. The voltage in question may be settled by simple measurements, as is detailed a little farther in the chapter when the question of overloading is discussed, but generally a resistance having a value equal to twice the valve resistance will be found satisfactory.

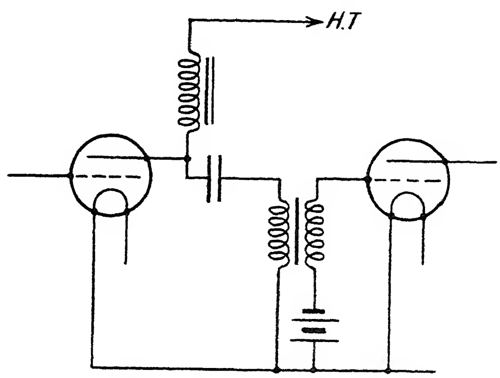

FIG. 11.—PARALLEL FEED CIRCUIT.

Saturation may, of course, occur in an output transformer or choke with equally unpleasant results. The only remedy in this case is to replace the suspected component with one of proved performance.

Incorrect Values

Another form of distortion arises from incorrect values of grid leak in resistance-coupled amplifiers. If the grid leak is too high, the phenomenon known as "grid choking," results. Although normally no grid current flows, certain peak values result in excessive grid potentials, and a small amount of grid current is taken at the top of these peaks. The effect of this is to increase the grid bias momentarily,

due to a building up of charge on the coupling condenser as with a grid rectifier, and on a strong signal the grid bias may be increased by quite a considerable amount. If the grid leak is of too high a value, this charge cannot leak away fast enough, and the speech or music has a choked sound. If on the other hand the grid leak is too small, then the bass reproduction suffers.

It is a good idea to check the values of the grid leaks and anode resistances of a resistance-coupled set. This may be done by the methods described in the Appendix, and the values actually found may be compared with the rated values of the component and these in turn may be compared with what is theoretically sound practice.

Two tables are given herewith which should be of assistance. The first of these is a list of the inductance of some of the better known transformers on the market. It should be observed that the inductance under working conditions should be 16 henries for the impedance at 100 cycles to be 10,000 ohms. Values at other frequencies are easily determinable by proportion. Thus, at 50 cycles, the impedance is 5,000 ohms, or conversely at 100 cyles, an impedance of 5,000 ohms would be obtained with an inductance of 8 henries.

The second table which is given herewith shows the correct values of grid leak and coupling condenser necessary to avoid a loss of bass. These values are such that the amplification at 50 cycles is 90 per cent. of the maximum, so that we have 10 per cent. cut-off in the bass frequencies. It will be observed that the value of grid leak and coupling condenser are interdependent, this being a factor which is not always appreciated. Provided that the values are of the order stated, therefore, satisfactory quality will be obtained and there will be no danger of distortion.

The anode resistance should be two to three times that of the valve, and the grid leak should be approximately four times the anode resistance. This immediately determines the correct value of coupling condenser, and in a well-designed set this is the order of the values which will be encountered. If the values are different then suitable alterations should be made and the effect noted.

A trouble which must be suspected in this connection is that the coupling condenser has broken down. The method

TABLE II

PRIMARY INDUCTANCES OF SOME REPRESENTATIVE L.F. TRANSFORMERS

Make	Inductance (Henries)	
	With no steady current	With 2 mA steady current
Brown	220	140
Mazda 2 : 1	120	80
4 : 1	60	35
Ferranti AF3	130	90
AF5	200	150
Igranic Type J 3 : 1	75	40
6 : 1	45	30
Lissen Super	150	80
Lewcos	120	90
Marconiphone 2.7 : 1	40	30
4 : 1	20	18
Varley Nicore II	40	30

TABLE III

RELATIVE VALUES OF GRID CONDENSER AND LEAK FOR 90 PER CENT. AMPLIFICATION AT 50 CYCLES (ONE STAGE)

Grid Leak (Megohms).	Condenser (μF).
0.5	.02
1.0	.01
2.0	.005
3.0	.0035
5.0	.002

of testing for this has already been described, but a partial break-down will result in the application of a small amount of positive bias to the succeeding valve, and this may distort the quality.

Battery Coupling

A final source of bad quality which may be found is that due to battery coupling. This is described more fully in the next section wherein it is pointed out that with even number of stages the battery coupling is positive, whereas with an odd number of stages the coupling is negative. In this latter case, it has the effect of reducing the total amplification, although the maximum reduction under the worst possible conditions is only something like 20 per cent. The danger lies, however, in the fact that the reaction effect is different at differing frequencies, and this naturally distorts the quality. Battery feedback may exist in a positive direction, but may be insufficient to cause actual oscillation, this depending upon the constants of the circuit. This type of distortion is even more unpleasant than the reverse feedback type, for it can be very violent in character, and may result in the accentuation of some frequencies and in the complete suppression of others.

Therefore, if all other ideas have proved unprofitable, battery-coupling should be suspected, and the remedy should be put into operation as described in the final section of this chapter, dealing with self-oscillation in L.F. amplifiers.

Overloading. Milliammeter Test

We have discussed the possible bad quality when the amplifier is operating on a weak signal. In many cases, however, the loss of quality only occurs when the amplifier is working on a normal or loud signal. In such a case, the problem is almost certainly due to overloading. This may arise from a number of sources, and it is necessary to go over the amplifier carefully in much the same manner as one does when looking for a definite fault.

A test which is of value in this connection is what is known as the "Milliammeter Test." A milliammeter should be connected in each of the anode circuits in turn. With no signals applied a certain anode current reading will be obtained. On the application of a signal this reading should remain

unaltered if the circuit is operating without overloading. The reason for this is fairly straightforward. Refer to the valve characteristic shown in Fig. 13. We choose for our operating condition a point on the curve such as that indicated by X. If we apply a symmetrical alternating voltage (not necessarily a sine wave) to the grid of the valve, we shall cause the anode current to increase and decrease alternately, the variations above and below the mean value being equal and opposite if we are amplifying faithfully. Consequently the mean value remains unchanged.

If, however, our operating point is incorrectly chosen or our grid voltage is excessive, we shall obtain asymmetry either due to the fact that we sweep on to the curved portion at the bottom of the characteristic, or due to the presence of grid current if we make the grid positive, and immediately this happens the mean value of the current changes.

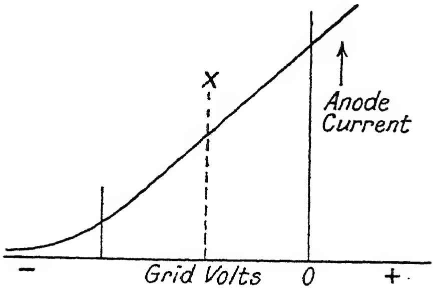

Fig. 13.—For Distortionless Working we Operate at a Point X on the Characteristic.

During the reception of a signal, therefore, the anode current will be found to fluctuate if any distortion is taking place, remaining quite steady if the circuit is functioning satisfactorily at the same value as with no signals applied.

In practical amplifiers it is rarely possible to provide such a good factor of safety as to obviate entirely any flicker or movement of the needle. On heavy passages the needle may kick momentarily, but this may be regarded as satisfactory, except in exceptional circumstances. If any real distortion is taking place, the needle will be in a state of continuous movement as opposed to merely an occasional flicker.

The test should be repeated on all the low frequency valves, but not, of course, on the anode circuit of the detector valve, for the whole principle of detection requires that the anode current shall change. By this means the trouble may usually

be located in one particular stage, although in severe cases every valve will be found to be overloaded.

Matching the Loud Speaker

If the output stage is found to be overloaded, the first consideration is whether the loud speaker is correctly matched to the valve. This is a point which cannot always be determined, for the manufacturers in this country do not, as a general rule, quote the impedance of their loud speaker. The maximum undistorted output is obtained when the speaker impedance is twice that of the valve. If this is not the case, then a transformer or tapped output choke should be used having a ratio given by the expression :

$$\text{Ratio} = \sqrt{\frac{2 \times \text{Valve Impedance}}{\text{Speaker Impedance}}}$$

This applies to small power valves. With increasing power, the valves have not such a good straight line portion to their characteristics, and in order to avoid distortion, it is necessary to use these valves at a lower efficiency and make the speaker impedance three, or even four times the valve impedance. Such special cases, however, are rather beyond the scope of this book, and the general rule given above will serve for the majority of cases.

Moving coil speakers do not vary greatly in impedance over the audio-frequency range. As a general guide, the impedance of the standard type of moving coil speaker may be taken as approximately twice the resistance of the coil.

With cone and horn speakers, the impedance increases greatly with the frequency, and it is necessary, therefore, to take the value at some particular frequency. Overloading occurs much more easily in the bass and, therefore, the impedance at some such frequency as 250 cycles is preferable for working out the correct matching of the loud speaker to the valve.

If the effective speaker impedance (that is to say the actual impedance multiplied by the square of the step-up ratio of the transformer) is greater than the optimum value (twice that of the valve), then the signal strength may be reduced, but distortion will not arise from this cause. If, on the other hand, the effective impedance is less than the

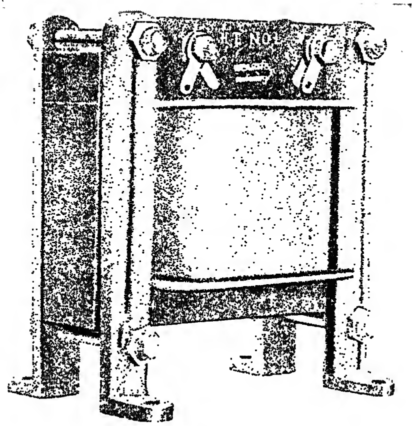

FIG. 12.—WEARITE CONSTANT INDUCTANCE CHOKE.

FIG. 14.—TYPICAL OUTPUT TRANSFORMER.

[*Facing page* 38.

optimum value, distortion will arise on strong signals, this form of distortion being usually known as blasting, which is a descriptive term indicative of the cracking or tearing noise which is set up owing to this particular form of overloading. Fig. 14 shows a form of output transformer having three possible ratios.

It is often suggested that the speaker itself is responsible for this overloading, but in the majority of instances this is not the case. Most modern loud speakers will handle far larger volume than they are called upon to deliver in ordinary practice, provided that the energy supplied to them is of satisfactory quality. This is not an invariable rule. Some loud speakers, for example, develop a rattle when the volume is increased, a fault that is particularly noticeable in some forms of moving coil speaker where the diaphragm breaks up into resonances in the upper frequencies as soon as the volume is increased. As a general rule, however, one need not suspect the loud speaker, because this is only rarely found to be the cause of the trouble.

If the overloading occurs in the earlier stages, the probability is that the grid bias is quite wrong, and this should be checked. The voltage actually on the anode of the particular valve should be measured, and by reference to the makers' figures, the grid bias should be adjusted to the correct value. If this does not cure the difficulty, then either the valve itself is faulty or the design of the circuit is wrong, and the valve is inadequate for the grid swing. It should be replaced by another valve having a lower resistance and consequently a larger permissible grid swing. The grid bias must be correspondingly increased, again by reference to the makers' figures, and this should overcome the difficulty.

The trouble may arise from the use of too small a voltage on the particular valve. This is often found to be the case where a parallel feed or resistance-capacity filter is used, so that the voltage on the anode of the valve is distinctly less than the full high-tension voltage owing to the drop on the resistance. Ensure that the valve has an adequate anode voltage by reducing the value of resistance or if necessary replacing it with an L.F. choke.

If the difficulty cannot easily be overcome, it indicates that the design is at fault, and this must be carefully rechecked

to ensure that each stage is working within its capabilities.[1] Alternatively, the input to the amplifier must be reduced so that the valves are not overloaded. It must be remembered that a small amplifier has its limitations in regard to the volume which can be delivered without distortion.

DETECTOR DISTORTION

So much for the low frequency amplifier itself. Distortion, however, can very easily arise as a result of the detector stage. The correct adjustment of the detector is a matter about which a great deal can be written. It is not proposed to deal with the subject in detail here, because at the time of writing, this component in the wireless receiver is receiving considerably more attention than in the past, and the art is, therefore, changing somewhat rapidly.

A brief survey of the subject, however, may be made and for this purpose we shall allocate the rectifier to one of two classes :

1. Grid rectification.
2. Anode bend rectification.

The grid rectifier is most sensitive to weak signals. The sensitivity starts at a good value, rises to a maximum, remains at or around this maximum for a certain period and then subsequently falls off very considerably. This curious configuration of the curve, illustrated in Fig. 15, is due to the fact that as the signal strength increases, a certain percentage of anode bend rectification occurs in addition to the grid rectification. The two effects act in opposition and ultimately almost cancel each other out.

[1] This may be done by working backwards from the output stage. The peak value of the grid swing on the output valve must not exceed the grid bias applied to the valve. The anode swing of the preceding valve is either equal to or some fractional value of this grid swing depending upon whether direct or transformer coupling is employed. In order that overloading shall not occur, the anode voltage on this valve must exceed this peak value of anode swing by at least 50 per cent. and possibly more, depending upon the straightness of the characteristics.

If one wishes to carry the analysis farther than this, the grid swing applied to this preceding valve must be some fraction of the anode swing, the actual value being determined by the effective amplification. From the knowledge of the circuit, some estimate may be made as to this figure, and by this means the probable grid swing (peak value) may be determined for this valve.

This process may be continued right back to the beginning of the amplifier.

Derived curves can be obtained from the sensitivity curve of Fig. 15, giving the L.F. current produced by varying strengths of modulated H.F. input, and Fig. 16 illustrates three such curves taken for PM1/HF, PM1/LF and PM2 valves assuming 20 per cent. modulation, operating with 50 volts actually applied to the detector anode. It will be seen that the rectification is substantially linear, that is to say, the L.F. output is practically proportional to the H.F. input up to a certain critical point, which is different for all three valves. At this point, the proportionality ceases, and indeed the L.F. output actually drops instead of continuing to increase.

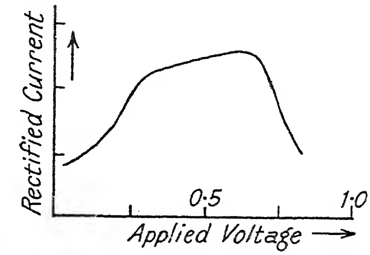

FIG. 15.—ILLUSTRATING VARYING SENSITIVITY OF GRID DETECTOR.

The detector is said to overload here and the quality is very badly distorted. The symptoms are usually a great accentuation of the sibilants and upper frequencies; this trouble entirely disappears if the input can be cut down in some suitable manner. Make sure that the detector anode is obtaining sufficient volts. The valve should have at least 30 and preferably 50 volts actually on the anode, as otherwise overloading will occur quite easily. With resistance coupling or parallel feed following the detector, the voltage on the valve is often reduced below this value. The remedy is to reduce the value of anode resistance, so that the voltage drop is reduced.

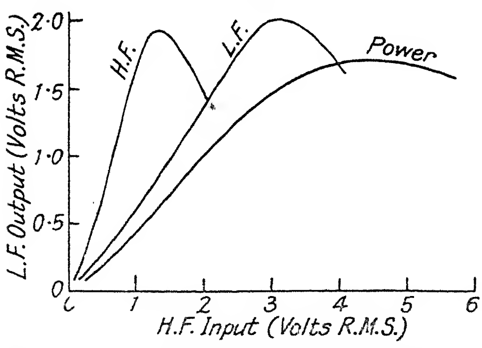

FIG. 16.—OUTPUT FROM REPRESENTATIVE DETECTORS (WITH 20 PER CENT. MODULATION).

A further symptom of this detector overloading is a double hump effect in the tuning, this phenomenon being illus-

trated in Fig. 17. The condenser appears to tune in the particular station at two distinct points, more or less close to one another according to the extent of the overloading. The reason for this is that as the signal strength increases when the circuit is brought into tune, so the rectification efficiency increases until at some point, not the actual resonance point, the critical value is reached. As the circuit continues to be tuned in, the H.F. component increases beyond this critical value, and the L.F. component therefore decreases in accordance with Fig. 16. Beyond the resonance point, the decrease in the H.F. component causes an increase in the L.F. component until the critical value is again reached, after which the circuit behaves normally. The effect, therefore, is to obtain a double-humped resonance curve, the peaks of which move farther away as we increase the input to the detector.

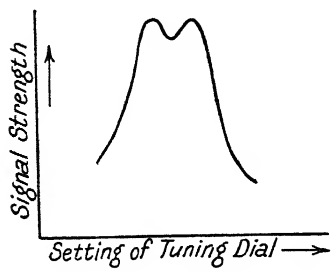

FIG. 17.—ILLUSTRATING DOUBLE-HUMP TUNING DUE TO DETECTOR OVERLOADING.

These two symptoms are usually sufficient to locate detector overloading, although the trouble may occur without the second symptom, i.e. only the accentuated sibilants may be observed. If an approximate idea of the actual voltage applied to the detector can be obtained, then the data given in Fig. 16 will indicate at once whether the valve is likely to be overloading or not, for the valves referred to are representative types.

The only remedy is to reduce the input in some suitable manner, either by inserting a wave trap to reduce the strength of the interfering station, or by incorporating a volume control on the H.F. stage, if any, of such a character as to reduce the magnification of the H.F. valve, and so reduce the voltage applied to the detector stage.

The second class of rectifier, the anode bend type, is insensitive to weak signals, but becomes progressively more sensitive to stronger signals since it obeys a square law. It has the advantage, however, that provided the voltage applied to the valve does not exceed the grid bias, no overloading will take

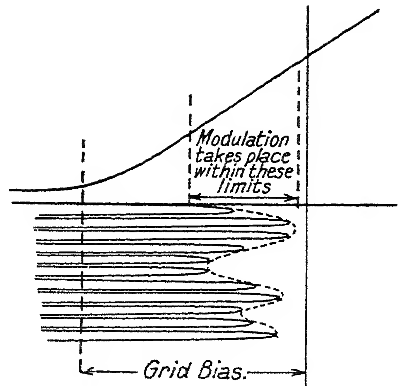

FIG. 18.—ILLUSTRATING LINEAR RECTIFICATION WITH THE ANODE BEND SYSTEM.

place, and for strong signals the sensitivity is rather greater than that obtained from the grid rectifier.

For obtaining good quality reception, a large anode voltage is applied to the valve and the bias is so arranged that the valve is operated under condition shown in Fig. 18. It will be seen that the unmodulated carrier wave is such as to make the peak value lie approximately in the middle of the "straight line" portion of the characteristic to the left of the zero grid bias line. If we modulate the carrier we now cause increases or decreases in the peak value of the current, but as the modulation is only partial in the great majority of cases, 20 per cent. to 30 per cent. being the customary figure in this country, the variations in the H.F. input take place over the straight portion of the characteristic, and the rectification, therefore, is linear.

This is satisfactory provided that one can apply a fixed strength of signal to the rectifier. If the signal falls below the critical value, one immediately runs into the curved portion of the characteristic and distortion results, while if the value is excessive, grid current will flow and distortion will again result. This particular form of rectification, therefore, is somewhat critical and liable to give rise to trouble, unless in the hands of an expert.

OSCILLATION IN L.F. AMPLIFIERS

We now come to the last form of trouble in amplifiers, namely continuous oscillation. This may be of various types, the oscillation ranging from a high-pitched whistle to a very low frequency "popping" often referred to as "motor-boating," owing to the similarity of the noise to the exhaust of a motor-boat engine.

Oscillation may arise due to actual coupling between the

various components. Low-frequency components, as a rule, are mounted on iron cores, and therefore the fields are confined. Nevertheless, it is possible with a circuit which is operating somewhat efficiently, for stray fields to leak back from the end of the amplifier to the beginning and set up a continuous oscillation or a tendency thereto. The difficulty is largely overcome by shrouding the components in iron cases or by earthing the iron core so that inter-action is only experienced in a very limited number of cases where the components have to be crowded together in a very confined space.

As a rule, therefore, it is better to test for other forms of trouble, before suspecting that this is the cause, but if tests appear to indicate that interaction is at the bottom of the trouble, the only remedy lies in the redisposition of the components. If the removal of one component and its reconnection some 2 ins. or 3 ins. away from its former position eliminates the difficulty, then the trouble is due to interaction and a suitable permanent position must be found for the component at which this interaction is minimised.

Battery Coupling

By far the most common trouble in low-frequency amplifiers is what is known as battery coupling. The circuit shown in Fig. 19 illustrates a two-valve amplifier, and it will be seen

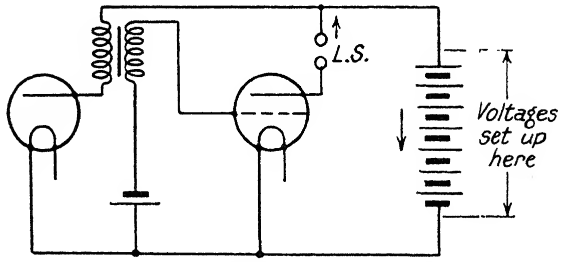

Fig. 19.—Illustrating Battery Coupling.

that the low-frequency currents having passed through the first valve and through the primary of the transformer return to earth through the battery. The voltages induced by these currents in the transformer are applied to the grid of the second valve and in turn we have a series of amplified currents

set up in the anode circuit of this valve. These currents in turn pass through the battery.

Now the battery is not of negligible resistance. It has a certain internal resistance which may be only a few ohms to start off with, but it may rapidly rise in practice to many hundred ohms. The currents in the last valve circuit passing through the battery develop a voltage across this internal resistance. This battery, however, is also a part of the anode circuit of the first valve, and therefore, these voltages are introduced into that circuit as well, setting up currents which will flow through the transformer primary in addition to the legitimate currents existing therein.

These additional currents must be either in opposition to or in assistance of the current already there. They may not be directly in or out of phase, in fact they are not likely to be, except in isolated instances, but their general tendency will be either to oppose or assist the existing legitimate currents. If they oppose, then the overall amplification of the circuit is reduced, while if they assist, the amplification is increased. The effect is cumulative, for increased amplification means more voltage applied to the last valve, more current through the battery, and consequently more feedback, and in quite a large number of cases the feedback is sufficiently great to cause a continuous oscillation.

The frequency of this oscillation depends upon the character of the common impedance. If it is a high tension battery, the oscillation is usually in the form of a high pitched whistle. In the case of a mains unit, which contains inductance and capacity in its smoothing circuit, the oscillation is usually of a much lower pitch and has a frequency of 3 or 4 per second only, whence the term " motor-boating " is derived.

It can be shown mathematically that with an even number of valves, 2, 4, 6, or more, the feedback is in a positive direction, tending to produce self-oscillation whereas with an odd number of valves, the feedback is negative. Positive feedback may still occur, however, between two adjacent valves.

The maximum decrease is limited to something like 20 per cent., but the fact remains that it varies with the frequency and, therefore, introduces distortion. In either case we must avoid this feedback, if we wish to obtain the most satisfactory results. The methods of combating the trouble are the same

whether the feedback is positive or negative, and are thus applicable to all forms of circuit.

De-Coupling Circuits

The method in general use is to provide filter circuits whereby the low-frequency currents do not pass through the battery or mains unit as the case may be. A simple method of achieving this on a two-valve amplifier is shown in Fig. 20. In the first case we use a choke-output circuit. The anode circuit of the output valve contains a high inductance choke of about 20 henries inductance, while low-frequency currents are by-passed through a large condenser (about 2 μF) and thence to the loud speaker. The low-frequency choke resists the passage of the L.F. currents, while, of course, the fixed condenser prevents the high tension battery from being short-circuited through the loud speaker. Thus we have a separation of the currents into their two distinct classes. The high-tension feed is obtained through the choke, and the low-frequency currents pass through the loud speaker where we require them. Since the L.F. currents do not go through the battery now, they do not develop the voltages and battery coupling is avoided.

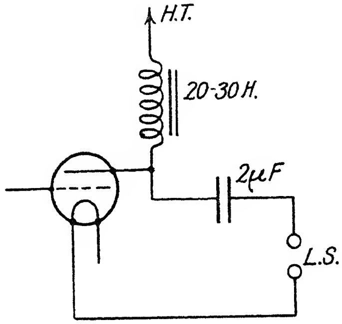

FIG. 20.—CHOKE OUTPUT CIRCUIT.

A somewhat similar method is shown in Fig. 21, where the filtering is applied to the first valve. A 50,000-ohm

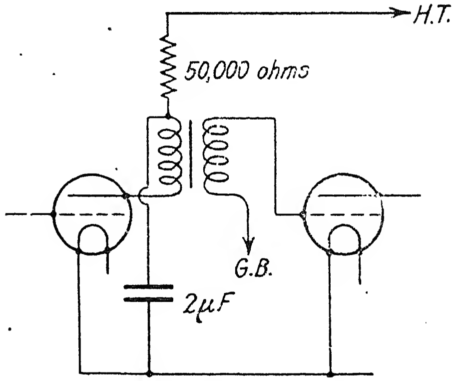

FIG. 21.—RESISTANCE-CAPACITY FILTER.

resistance is connected in series with the H.T. supply, and the junction point between this resistance and the normal circuit is by-passed to earth through a large condenser of $2\mu F$. The low-frequency currents having passed through the primary of the transformer prefer to go through the $2\mu F$ condenser to earth since this only has a reactance at 100 cycles of 800 ohms, which is much smaller than the 50,000-ohm resistance. The voltage applied across the whole circuit must, of course, be the full amount in order to allow for the voltage drop in the 50,000-ohm resistance. Otherwise the valve will not obtain adequate voltage on the anode itself.

Choke de-coupling may be used on the earlier stages as well as on the last stage if necessary, and both devices may be

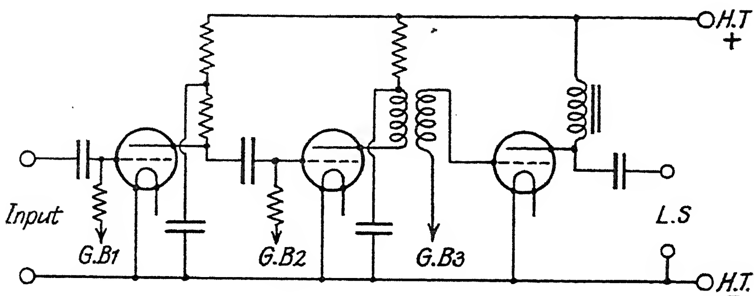

FIG. 22.—3-STAGE DE-COUPLED AMPLIFIER.

resorted to concurrently. Fig. 22 shows a 3-stage amplifier in which each stage has been de-coupled, the first two with resistances and the last with a choke.

If, therefore, a whistle is obtained in a low-frequency amplifier, battery coupling is one of the first things to suspect. It may be cured by de-coupling the circuit in the manner already described, and in fact, any amplifier which is not so de-coupled will be improved in performance provided the de-coupling is carried out in a satisfactory manner. It may perhaps be remarked, in passing, that distortion produced by battery coupling is not indicated by a milliammeter, whereas distortion due to overloading is indicated at once by the lack of steadiness in the anode current.

Battery coupling is not only troublesome in low-frequency stages, but also in high-frequency circuits, and the methods

of de-coupling in H.F. circuits are dealt with in Chapter V. It is relevant to remark, however, that if the same battery is used for both high-frequency and low-frequency stages, as is nearly always the case, high-frequency voltages set up by the H.F. currents flowing through the battery are introduced into the low-frequency stages and this is another means by which H.F. currents can be introduced into an L.F. amplifier. The only method of keeping them out is to treat them at the H.F. portion by de-coupling the H.F. stages, and in order to ensure that no trouble is being experienced in this direction, it is desirable to disconnect the H.F. stages or render them inoperative by taking out the H.F. valves when checking over the amplifier in order that one shall not obtain conflicting effects, tending to mask the real source of difficulty.

SUMMARY

1. *Amplifier refuses to function.*—Check anode current, noting that each valve takes its due share. Check the voltage on each circuit from H.T. Battery down to anode of each valve, working progressively backwards till the fault is discovered.

Alternatively, or in addition, test each stage in turn on signals working from the input to the output, if the radio portion is in order, or working back from the output end with a gramophone pick-up.

2. *Amplifier howls.*—Suspect broken grid circuit. Otherwise probably battery coupling. Find by elimination which stage is causing trouble. Use new battery or de-couple stages.

N.B.—A whistle may be caused by high-frequency energy in the L.F. stages. Adopt customary precautions to obviate this.

3. *Amplifier operates with bad quality.*—If reproduction is strangled or choked, suspect broken grid or complete break in a vital portion of the circuit. If quality is thin and reedy suspect presence of high-frequency energy. Examine values of components replacing where necessary temporarily. Discriminate between bad quality and overloading. Test for the latter with milliammeter. If no obvious fault, suspect

battery coupling and adopt usual remedy. Ensure detector is not overloading. Measure voltage on detector. Increase if necessary.

4. *Amplifier operates with little power.*—Check every component through systematically, including valves.

CHAPTER IV

Tuning Tests

Having proved the low-frequency side of the set to be satisfactory, attention may be turned to the H.F. side for the location of the fault. In this region one of the most useful accessories is the wavemeter, which was described in Chapter I. This is simply a source of high-frequency energy which may conveniently be introduced into the circuit at different points in order to ascertain whether each portion of the circuit is working correctly. It takes the place of the gramophone pick-up in the low-frequency section.

In many cases, however, it is possible to locate the fault without having recourse to the wavemeter, use being made of the transmission from the local broadcasting station which is usually of sufficient power to enable one to obtain adequate voltage for testing. As in the low-frequency stages, a systematic testing of the functioning of each portion of the circuit, working backwards in this case from the detector valve to the front of the set, is the only method of procedure. One very important difference, however, may be emphasised, and that is that the alteration of connections may make a very material difference to the operation of the set.

Effect of Alterations on Circuit

To take a practical example, a convenient test and one with which I usually start myself in any high-frequency circuit which is not functioning correctly, is to connect the aerial system through a small condenser to the grid end of the detector tuning circuit. This operation will be described shortly. The point to be emphasised is that this very action will completely alter the tuning of the detector circuit. Therefore, in interpreting the results obtained from this test, due allowance must be made for this factor.

Small capacity effects are of great importance at high frequencies, and one has, in general, a more elusive form of energy to deal with prior to the detector. A little more thought, therefore, is usually required in locating high-frequency faults in order to interpret correctly the results obtained from the various tests.

Now let us discuss, as we did in the low-frequency case, one or two hypothetical cases. We will take first of all a simple detector circuit in which there is only one tuning circuit in front of the detector. Let us assume that the circuit is of the form shown in Fig. 23, from which it will be seen that the aerial is coupled by means of an auxiliary winding to the tuned circuit itself. A reaction coil is coupled to the tuned winding, the reaction effect being controlled by means of a variable condenser.

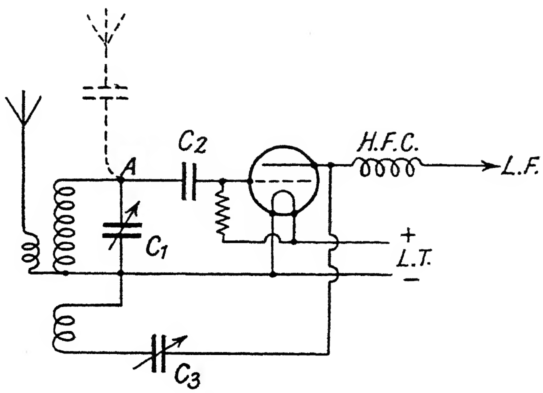

FIG. 23.—SIMPLE DETECTOR CIRCUIT.

There are numerous faults which can apply in a circuit of this type. It may, for example, refuse to function altogether, it may function weakly or the trouble may lie in the reaction circuit so that one can obtain the local station but no foreigners or distant reception. The method of procedure is the same throughout, that is to say a gradual elimination of the various faulty parts of the circuit.

Checking the Tuning

First of all, the thing is to test out the tuning circuit. Remove the aerial from its terminal and connect it through a ·0001 μF condenser to the grid end of the tuned circuit—the point marked A in the diagram. The object of using a ·0001 μF condenser is to reduce the capacity of the aerial, for the

aerial is now connected across the whole circuit. The aerial has a certain capacity, usually lying between ·0002 μF and ·0003 μF, and the effect is to alter the tuning of the main condenser which is usually only ·0005 μF and may be even less. If one requires to tune in a station which normally needs a capacity of, say, ·00015 μF only, then the connection of a large condenser of, say, ·00025 μF across the whole circuit due to the aerial will, of course, prevent the circuit from tuning altogether,[1] for even in the minimum position of the variable condenser we are unable to reach such a small capacity as ·00015 μF.

The insertion of a ·0001 μF condenser in series with the aerial reduces its effective capacity to something like ·00007 μF or even less, depending upon the aerial capacity, and this does not have too serious an effect upon the tuning of the circuit. One cannot achieve the same minimum which would otherwise be possible, but provided the station required normally tunes in about the middle of the scale, it will still be found possible to tune it in, although it will now be some 20 or 30 degrees lower in its tuning position.

With aerial and earth connected in this manner, the circuit should receive signals from the local station without any difficulty, even if the reaction circuit is not functioning satisfactorily. If the local station is too weak, or is not available, then bring the buzzer wavemeter into play, and tune it to a wavelength in the neighbourhood of 400 metres. Then on bringing the wavemeter near to the detector circuit, no difficulty should be experienced in tuning in the note from the buzzer.

Connections to Detector Valve

If no reception can be obtained in this condition, either the tuning circuit itself is at fault, or the connections between the tuning circuit and the detector valve are incorrect. Check the grid condenser, and make sure that this shows an open

[1] It must be remembered that when two capacities are both across the same circuit, in parallel as it is called, the total capacity is the sum of the two individual capacities.

Similarly if two capacities are placed in series, the resultant capacity is smaller than either of them and is given by the expression :

$$C = \frac{C_1 C_2}{C_1 + C_2}$$

circuit, indicating that the condenser is not short-circuited. This does not, of course, show whether the condenser itself is sound, for a complete break inside the condenser would give just as good an indication on this form of test as a proper condenser. In order to ensure that the condenser is really satisfactory, an additional condenser of say ·0002 μF capacity should be connected across the grid blocking condenser, that is to say, in parallel with the condenser C2 in the figure. If the original condenser has broken down, this condenser will take its place and rectification will be produced. If, on the other hand, the condenser was all right, this condenser will have no effect so that a positive indication is obtained one way or the other.

Assuming that by this method we have proved the grid condenser circuit O.K., then attention should be turned to the tuning coil. Test the continuity of the coil (see Appendix). If this is broken, then the damage must be found and repaired. See that the coil is correctly connected to the tuning condenser and check the insulation of the condenser by seeing that it registers an open circuit on the continuity tester. For this purpose, of course, the coil must be either removed or disconnected as this, being normally connected across the condenser, will cause a short circuit indication to be obtained unless it is removed. If the condenser does not show an open circuit when tested in this manner, then the plates are touching somewhere or some other short circuit exists across the condenser, and this should be located and removed.

When all these points have been looked to, no difficulty should be experienced in tuning in either the local station or the buzzer signals, according to circumstances, and this indicates that the tuning circuit is correct.

Checking Reaction

The next procedure is to check out the reaction control. If this does not function, then the coil should be tested for continuity, and also for direction if it is visible. If it is not visible, then the only test which can be made is to reverse the leads to the coil and see if any better results are obtained. Where the coil is visible, however, it is always possible to check it by the following simple rule. The winding on the grid and anode coils should be continuous in direction. For

example, if one starts at the grid point of the circuit and the winding goes clockwise to the filament, then it should continue to go clockwise from the filament (or H.T. +) to the anode. If the winding goes clockwise as far as the filament, and then the reaction coil traced from the filament (or H.T.) end to the anode end, goes in the opposite direction, the winding is in the wrong direction to produce oscillation.

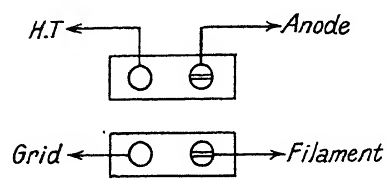

FIG. 24.—CONNECTIONS TO PLUG-IN COIL HOLDERS FOR CORRECT REACTION.

Where plug-in coils are used, the diagram shown in Fig. 24 gives the correct connections of the coil holders to produce reaction. This is very handy, and will save a good deal of difficulty. The plug of the grid coil is shown going to filament, which is the correct connection where an X coil is used (except Igranic—see later), but actually either coil holder may be turned round at will, provided the connections remain as shown and are *not* reversed also.

If the coil is correctly connected and is continuous, then if nothing happens at all, the circuit is broken at some point or another. If the reaction effect tends to increase signals, but is weak, then a larger value of condenser should be used to control the oscillation. Alternatively in the case of a swinging coil reaction, a larger coil should be used or a by-passing arrangement should be inserted (see page 57).

Having obtained the tuning circuit and the reaction circuit correct, it now remains to see that the aerial coil is right. Remove the aerial from its present position and connect this to its proper terminal, removing the ·0001 μF condenser. Results should now be satisfactory, but if they are not, then test the aerial coupling coil for continuity. It must be remembered, of course, that with a coupled aerial circuit, the results are usually distinctly weaker than with the aerial coupled straight on to the grid end of the coil through a ·0001 μF condenser. It is possible with a coupled aerial winding to get much the same strength as with a ·0001 μF condenser, but it is more usual to arrange matters to give rather less strength than this in the interests of selectivity. Therefore, a

certain drop in signal strength may be anticipated, but if the drop is serious, the aerial coupling is insufficient, or, possibly, too great since too many turns give the same effect.

Incorrect Tuning

It may be found that the circuit does not tune correctly when the aerial is connected to its proper terminal. This usually indicates that the aerial coupling coil has become connected to the wrong end of the tuning coil. If this is connected to the grid end, then it is clear that the aerial capacity has been connected across the whole coil, as in Fig. 25, and as has already been pointed out, this completely spoils the tuning properties.

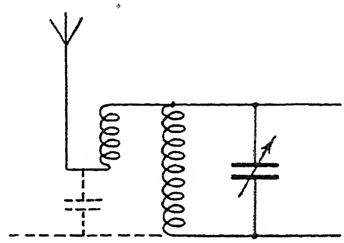

FIG. 25.—IF THE AERIAL COIL IS CONNECTED TO THE WRONG END OF THE SECONDARY COIL THE TUNING WILL BE UPSET.

Difficulties of this nature are often obtained with X-tapped coils, the coil being so arranged that the X-tapping is at the wrong end of the coil. The circuit shown in Fig. 26 illustrates the correct method of connection of the coils so that the tapped portion shall be at the bottom end of the coil, which is what one requires. This is the standard connection as used by Lissen, Lewcos, Atlas and many other plug-in coils. The Igranic plug-in coil, however, follows the opposite convention, and this is a point which must be borne in mind. The connections, therefore, for an Igranic plug-in coil are the reverse of those shown in Fig. 26, but this is the only well-known make which is different from standard.

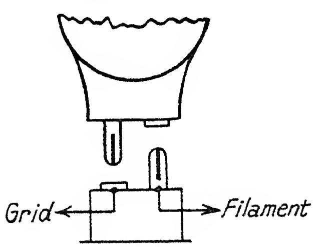

FIG. 26.—CORRECT CONNECTIONS FOR X COILS. PLUG OF COIL HOLDER IS CONNECTED TO L.T.

Other difficulties which can occur with quite simple variants of the simple circuit shown in Fig. 23 will readily suggest themselves to the reader. For example, in many cases, one side of the reaction coil is permanently connected to one side

of the tuning coil. If by any chance this coil is connected the wrong way round, so that the grid end is connected to earth and *vice versa*, not only will the aerial coil be wrong, as already mentioned, but the reaction will obviously be incorrect, and although the reaction coil gives a " continuous " test and the remainder of the circuit appears to be in order, the results will clearly not be satisfactory.

SEPARATION OF H.F. AND L.F.

The detector valve itself is a fruitful source of trouble, for here the H.F. currents are rectified, giving rise to low-frequency variations in the anode current. These latter variations we utilise and apply in the L.F. stages, while the H.F. currents are no longer required and must be sidetracked.

The detector valve, therefore, must be an efficient amplifier of both forms of current, and the anode circuit must contain two paths, one of easy access to the L.F. currents, yet presenting a high impedance to the H.F. energy, and the second doing just the opposite.

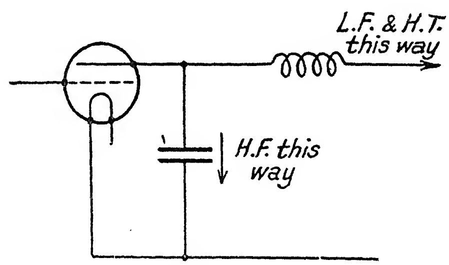

FIG. 27.—SEPARATION OF H.F. AND L.F.

In many cases the provision of an easy path for the H.F. current is overlooked, which gives rise to instability or poor quality in the L.F. stages, and prevents the detector from developing its full efficiency.

The simplest method of separating the two types of current is shown in Fig. 27, where a divided circuit is employed. The L.F. currents pass through the main circuit, which contains a high-frequency choke to act as a barrier to the H.F. currents. These, therefore, pass through the by-pass circuit—a small condenser between anode and L.T—. This condenser must have a value sufficiently high to provide a ready by-pass action while being small enough not to affect the L.F. appreciably. A value of ·0002 μF is usually satisfactory.

Reaction Circuits

Instead of deliberately wasting this energy we may make use of it to provide a certain amount of reaction, and this gives rise to the capacity-controlled reaction arrangement in common use. The energy is not shunted directly to L.T.—, but is passed through a small coil suitably coupled to the tuning coil. At the same time, in order to control the amount of current which flows in this circuit, the condenser is made variable. If this is very small, then only a small current flows and little reaction effect is obtained. As the capacity is increased, more and more current flows, giving an increasing reaction effect, always assuming that the coupling coil to be in the right direction.

In general, however, the amount of current required for the production of a reaction effect is not sufficient to by-pass the high-frequency energy completely, and therefore it is desirable either to include an additional condenser from anode to L.T.—, or alternatively to use a differential reaction condenser. This latter device is a double condenser so arranged that as one capacity increases the other decreases. One portion is used to control reaction effect, while the other is used as a by-pass between the anode and L.T.—. The net result is that the total by-passing of the high-frequency energy either through the reaction circuit or through the direct path is constant.

Moving coil reaction is often employed instead of capacity-controlled reaction. With this system, however, the high-frequency currents, after passing through the reaction coil, must have a suitable easy path to earth. When they reach the transformer primary, they are held up by the inductance of the winding. The only route available is the relatively high-impedance path afforded by the self-capacities in the

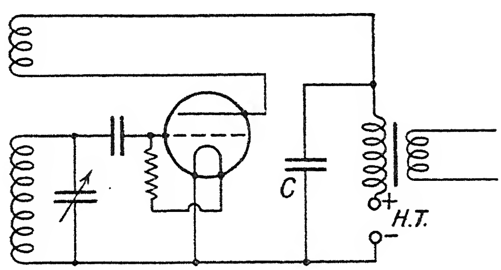

FIG. 28.—ILLUSTRATING USE OF BY-PASS CONDENSER ACROSS TRANSFORMER.

circuit. To provide an adequate path for the current, a condenser should be connected across from the anode end of the transformer primary to L.T.— as shown in the circuit in Fig. 28. The connection of a condenser in this manner across the transformer will often be found to make a circuit oscillate where in the ordinary course of events it will not do so.

This tip is useful in connection with many dual-range tuners, where a number of sections of the coil are all wound on the same former, certain portions being short-circuited by means of the switch, in order to tune to the lower wavelengths. A common reaction coil is usually provided in this class of tuner, and the winding has to be rather delicately proportioned so that it will be sufficient for the coil with its maximum inductance and yet shall not be too fierce when the coil is adjusted for the shortest wavelengths. Loss of reaction is quite a common experience with this class of tuner, and the connection of a condenser across the transformer primary will often be found to clear up the difficulty altogether.

H.F. Chokes

These comparatively simple separating arrangements may give rise to a considerable amount of trouble, if the circuit is not correctly arranged. One of the principal difficulties arises from inadequate high-frequency chokes. An H.F. choke, to be effective, must have a high inductance and a low self-capacity. The problem is aggravated in this country by the fact that we have to cover a large band of wavelength ranging from 200 to 2,000 metres, and the production of a device capable of exercising a high impedance over the whole of this band is a matter requiring a certain amount of designing skill.

A high-frequency choke is often spoken of as an inductance, but it is incorrect to regard it in this light. It is admittedly an inductance from the point of view of low-frequency current, but at radio frequencies the self-capacity of the winding is of greater importance. There is one particular frequency at which the self-capacity of the winding resonates with the inductance. At this point the maximum choking effect is obtained, and at all frequencies above this point (wavelengths lower than the resonant wavelength) the arrangement acts to an increasing extent as a small capacity. The limiting

value of this capacity is the self-capacity of the choke itself, which in a good sample is of the order of two or three $\mu\mu$F only. Thus a good high-frequency choke under working condition is really a very small capacity which has the property of allowing the direct current or low-frequency current to flow through it.

For a choke to be really satisfactory in practice its inductance must be at least 100,000 microhenries, and preferably more, and this self-capacity should not exceed three or four $\mu\mu$F.

The evils which result from the use of an inadequate choke are many and varied. One of the first is the failure to produce a sufficient reaction effect. The second result often encountered is that the reaction circuit has what is sometimes known as " holes." These are spots where the set refuses to oscillate or alternatively where it oscillates very violently and uncontrollably. These usually indicate that the main resonant point or some very strong harmonic resonant point of the choke has occurred within the wavelength range being received.

Another difficulty brought on by the use of an inadequate choke is low-frequency growling. This is more particularly noticed when the circuit is brought to the threshold of oscillation, when a very unpleasant growling is set up, which prevents the circuit from being used in a sensitive condition. The trouble is due to high-frequency energy being passed into the L.F. stages and although it can sometimes be cured by taking certain precautions in the low-frequency stages, the best cure is by the alteration of the choke itself.

In many manufactured sets the use of a really adequate choke is avoided on the score of cost. If the designer is thoroughly conversant with his art, he can in many cases do this by making other components in the circuit assist him. Nevertheless this factor is one which can cause a great deal of trouble, particularly with home-constructed equipment.

The present remarks are concerned more particularly with choke which is used following the detector valve in a receiver. In the case of choke-coupled high-frequency stages, the problem is somewhat different, and this point will be discussed in the next chapter.

Backlash

An effect which may be experienced with tuning circuits is backlash or "ploppy" reaction. The former is the effect obtained when the points at which the set commences and ceases to oscillate do not coincide. As the reaction control is increased the circuit will oscillate at a certain setting, but the control must be retarded several degrees before the oscillation ceases. "Ploppy" reaction is a milder form of the trouble in which the oscillation starts suddenly, whereas for best results the amplification should be capable of being increased gradually and progressively until the circuit gently slides into oscillation.

The avoidance of these undesirable features is largely a matter of design, but conditions can be improved by altering the value of the grid bias applied to the detector. Where grid rectification is employed, the grid leak (or circuit return) should not be taken to L.T.+ as is usual, but should be connected to a potentiometer across the filament circuit and only a fraction of the full voltage applied. Usually about one quarter to one half of the full L.T. voltage will be sufficient to give a combination of good strength and smooth reaction.

Broken Grid

I am not a believer in the use of tabulated tests, from which one can diagnose faults by the noise which emanates from a receiver, when one pokes a finger on to various vital points. The systematic application of commonsense may be less romantic, but it is safer. There are, however, a few simple effects which may be mentioned as time savers.

Firstly, a broken grid circuit on a detector valve is usually accompanied either by a definite howl or squeal or by an increased sensitiveness to extraneous disturbances. If there is any electric light in the house, the peculiar humming noise known as "mains hum" will almost certainly be picked up quite strongly. The grid circuit is lively, and if the grid terminal of the valve is touched a shriek is usually set up.

Similar symptoms are experienced if the grid leak is of too high a value.

Oscillation Tests

A rough and ready test for oscillation is often useful.

Touch the grid terminal or grid side of the tuning condenser. A loud click will be heard in the loud speaker or telephones if the circuit is oscillating, but otherwise only a soft "plop" will result. This test is often useful in a set with several H.F. stages, one of which is oscillating, when it will show which circuit is offending.

This test depends on the fact that the anode current changes when the circuit oscillates; the placing of the finger on the grid or live side of the circuit stops it oscillating, and therefore causes a sudden change in anode current. A more scientific test is to place a milliammeter in the anode lead of the particular valve and to note the anode current. This will nearly always change considerably when the circuit commences to oscillate. In some cases (such as an H.F. valve) an increase results, while in others—notably a grid detector—the current will decrease.

SUMMARY

1. *Circuit fails to tune.*—Couple aerial to circuit directly through ·0001 μF condenser, or alternatively use buzzer wavemeter. If circuit still fails to tune, investigate circuit for disconnection. If circuit is found O.K., trouble lies in system utilised for coupling to the circuit (i.e. aerial coupling system, or primary if an H.F. transformer).

2. *Circuit tunes, but strength is weak.*—Connections between tuned circuit and valves are defective. Alternatively the valves themselves are defective.

3. *Circuit tunes, but in wrong manner.*—Fault in circuit is due to presence of additional capacity or other extraneous influence, such as switch not working correctly on a dual-range coil. See that the coil is connected the right way round. Isolate coil from the circuit as far as possible, leaving it connected to the valve only. Check tuning with wavemeter, or with aerial connected through a ·0001 μF condenser.

4. *No reaction.*—Reaction circuit wrongly connected or faulty. Alternatively detector at fault or too heavily by-passed.

5. *Threshold howling.*—Inadequate H.F. choking or inadequate by-passing. Operating point on detector valve may

be changed with advantage by altering grid leak or connecting to a potentiometer across the filament.

6. *Backlash or ploppy reaction.*—Grid potential wrong. Connect grid leak or circuit return to suitable point on potentiometer across filament circuit. Alternatively reduce H.T. volts on detector.

7. *Undue pick-up of interference accompanied by weak signals.*—Broken connection between tuning circuit and valve. Alternatively too high value of grid leak.

CHAPTER V

High Frequency Tests

We have discussed the simple tests to be made on a single circuit receiver incorporating a detector valve followed by low-frequency stages. In many cases high-frequency amplification is employed prior to the detector stage, and various faults may arise in this portion of the receiver. The high-frequency amplification employed may be of two general kinds:

1. Tuned amplification, in which the various stages are individually tuned to the signal being received.

2. Untuned, in which case the circuit has no specific tune, but may be arranged to give some form of broad resonance within the frequency band under consideration.

The former type of circuit is utilised in the general run of receivers intended for operation on external aerial systems, while the second type is commonly employed in portable and transportable receivers. The methods of operation of the two classes of circuit are somewhat different, so that they are best considered separately.

TUNED AMPLIFICATION

Turning our attention, therefore, to the tuned variety of circuit, there are again two forms of circuit. In one, a standard three-electrode valve is employed, with some form of neutralising or stabilising device. In the other the necessity for this is obviated by the use of a screened-grid valve. The methods of testing are similar, but the former case requires certain special additional tests. We will, therefore, deal with the matter primarily from the point of view of the screened-grid valve, and will consider the neutralised triode afterwards.

Let us consider first one of the simplest forms of a tuned anode circuit utilised with a screened-grid valve. This is as

shown in Fig. 29. We have, of course, two tuning circuits to contend with, the first in the grid circuit of the valve, and the second in the anode circuit, the voltage developed across

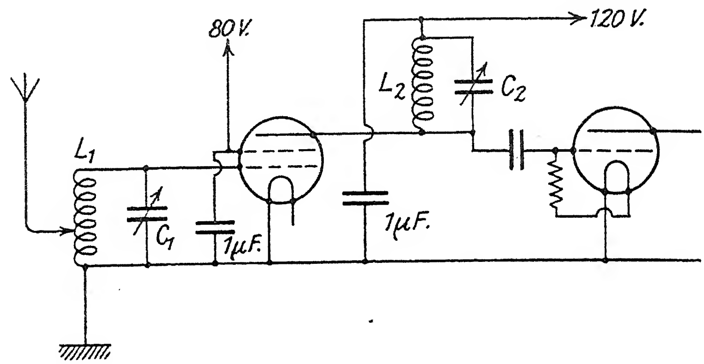

FIG. 29.—SIMPLE TUNED ANODE CIRCUIT WITH S.G. VALVE.

this second circuit being transferred to the detector valve. The faults which we can encounter here may be divided into two classes:

1. The circuit refuses to function satisfactorily.

2. The circuit is unstable. When the circuits are brought into tune, the arrangement bursts into oscillation.

We will consider the two possibilities in turn. As a general rule one can obtain some idea of the location of the trouble by the behaviour of the circuit. It is often found, for example, that one circuit appears to tune satisfactorily, whereas the other does not. This saves a certain amount of trouble in locating the cause of difficulty, for it is the circuit which fails to function correctly, or some portion of the circuit immediately associated therewith, which is defective. Assuming that no such short cut is possible, however, the method adopted must be the standard process of elimination.

First of all remove the H.F. valve from its holder, disconnecting the lead between the anode of the valve and the coil. It may perhaps be remarked in passing that this lead is connected through the circuit to H.T. +, and care must be taken, therefore, to avoid a short circuit, if this lead is allowed to lie with its end free.

The circuit is now, to all intents and purposes, a simple detector circuit. It is a little unusual, in that the low potential end of the circuit is not connected to L.T. but to H.T.+. Provided there is a large condenser across the battery, however, this makes no difference to the operation of the circuit. We can use a wavemeter for testing or transfer the aerial from its normal position to a suitable point on the detector. This may be done by connecting the aerial through a ·0001 μF condenser, on to the grid end of the tuning coil (not to the grid of the valve). This will cause an alteration to the tuning, as mentioned in the last chapter, owing to the fact that the effective aerial capacity of some 70 to 80 $\mu\mu$F will be in parallel with the tuning condenser, but this is of little consequence for the purpose of the test. The circuit should then be tuned in the customary manner. It should tune over its appropriate wavelengths without difficulty, and the reaction control, if any, should operate cleanly and smoothly, causing a definite increase in the signal strength up to the point where the circuit slides into oscillation.

If this is not so, the first thing to do is to make sure that there is an adequate by-pass across the H.T. circuit. This should be done by connecting a large condenser (1 μF) across from the H.T.+ point on the coil to L.T.—. It should be emphasised that the condenser should be connected to the H.T. point on the coil itself, and not merely across the H.T. battery. This is of more particular interest in short wave work (see Chapter VII).

If the difficulty still persists, the tuning circuit itself must be examined for faults in the manner already described in the last chapter. By analysing the circuit in the manner outlined therein, the cause of the difficulty may be located and remedied.

If the tuning circuit in the detector stage is O.K., or if we have located and corrected a fault therein, the H.F. valve maybe re-inserted and connected up. It is assumed, of course, that the valve has been tested in accordance with the data already given (see Chapter II). The re-insertion of the H.F. valve completes the whole circuit, but it is as well to test the tuning of the detector stage once again, in order to ensure that the mere connection of the H.F. valve into position has not introduced some difficulty. Such things can happen

owing to faulty valve holders or wires short circuiting or something of this nature. Such faults are not usual, but they *are* experienced and are all the more bothering when they are encountered. Hence it is as well not to take anything for granted, but to make quite sure that the mere act of inserting the H.F. valve has not re-introduced the trouble.

Assuming, however, that this is not the case, we can now turn our attention to the H.F. tuning circuit. It is advisable to tune the detector stage to some particular signal, and then endeavour to tune the H.F. circuit to the same signal. This it should do quite satisfactorily, but if it does not, then the tuning circuit itself is at fault. The same tests must be applied as were detailed in the last chapter for the simple tuning circuit, and on this basis the faulty portion of the circuit should be located without difficulty. Working backwards we can ensure that the tuning coil itself is correct, and ultimately we can connect the aerial system, completing the chain when everything should be satisfactory.

LOSS OF POWER

Perhaps the more difficult type of fault to locate is that in which the circuit only works in a half-hearted manner. One has to find out exactly where the trouble is seated, and then to rectify the mistake. We will assume that the difficulty has been located in the high-frequency stages, the L.F. stages having been eliminated by the processes already described. The detector stage should also have been eliminated, but it is as well to make sure of this point at an early stage of the proceedings.

The decision as to whether the detector stage is functioning satisfactorily is a matter which can only be decided by personal knowledge. The operator will be aware from his own experience of the performance likely to be obtained on a simple detector circuit followed by whatever low-frequency stages the particular receiver possesses. Thus, if we have a receiver having one resistance-coupled and one transformer-coupled low-frequency stage, then if the detector circuit is isolated in the manner previously described, the circuit becomes a straight 3-valve set. The strength at which the local station would be received on an arrangement such as this, the distant stations likely to be received and so on, will be known to the

operator, and no more definite test than this can be given, unless one is in possession of some standard form of signal for testing, such as is used in a laboratory as outlined in the second portion of this book.

If the detector circuit is not found to be functioning satisfactorily, then one must exercise the same process of elimination to discover which component is faulty. Perhaps one of the most fruitful sources of trouble in the simple detector circuit is the failure to by-pass the high-frequency current adequately. In the last chapter the desirability of connecting a condenser between the anode of the detector valve and L.T.— was discussed. Incidentally this condenser is not deleterious to reaction, and distinct increase in signal strength will usually be observed upon connecting such a component in circuit. For the detector to operate satisfactorily it must be a good amplifier, both of high- and low-frequency current, and the connection of a by-pass condenser in this manner assists the detector in its amplification of the high-frequency component. The value should not exceed ·0003 μF, as otherwise there is a danger of shunting an undue proportion of the upper low frequency currents.

Another source of difficulty in the detector stage is the grid leak, if grid detection is being employed. If this is of too low a value, the signal strength may suffer considerably, and no harm is done by changing the leak. It is sometimes desirable to ensure that the insulation of the grid condenser is satisfactory, and this may be done by isolating the condenser temporarily and putting across it the standard test for grid leaks (see Appendix). If there is any leak across the circuit this will show up at once.

Checking the H.F. Amplification

If we assume, however, that the detector circuit is O.K. or has been made to operate satisfactorily, and if the results of the whole circuit are still not up to standard, then we must make some test on the amplification being obtained from the screen-grid valve. This again can only be done in a comparatively crude manner, unless one has laboratory apparatus at one's disposal. The simplest method, however, is to use the signals from the local station for the purpose of test, assuming that this station is sufficiently close for the transmission to

be constant. Use a small aerial system consisting of a short length of, perhaps, 2 ft. to 6 ft. of wire, and connect it directly to the grid end of the detector circuit. A length of wire should be so chosen that in this position the local station can *just* be tuned in, preferably without any reaction.

Now transfer this short aerial to the high potential (grid) side of the H.F. circuit. The local station should now be capable of being tuned in at good strength, and there should be a distinctly marked increase in the volume, due to the amplification obtained from the high-frequency stage. If this is not so, all the various components in the H.F. stage must be examined in detail in order to find which component is causing the trouble. In cases where the fault is not immediately obvious, it is a good plan to disconnect the tuning system altogether, and to connect up entirely separate tuning circuit external to the receiver. This may be made with a plug-in coil and an external condenser, and should be connected across the grid and filament of the H.F. valve in the customary manner. If the signal strength received on this arrangement is good, whereas on the standard arrangement it is poor, then something is incorrect in the tuning circuit itself, and a little experiment should bring to light the defect.

If loss of power is still evident after all the normal tests have been applied without bringing any defect to light, the inefficiency is probably due to battery coupling and the remedies discussed later in this chapter should be tried.

These remarks will give a general idea as to the method of testing an H.F. stage. Whether there is a definite fault or whether the amplification is poor, the methods should be of the nature outlined. The same remarks apply to a number of H.F. stages. Moreover, the same procedure is applied whether we are using a screen-grid valve or a neutralised triode.

H.F. Transformers

The circuit considered was a simple tuned-anode arrangement only. The methods adopted are little different if a tapped coil or an H.F. transformer is employed. A little more care must be taken in the process of elimination to avoid jumping to conclusions. For example, let us consider the

H.F. transformer arrangement shown in Fig. 30, which differs in several particulars from that of Fig. 29.

The first step is to test the detector circuit as before. Connect this aerial through a ·0001 μF condenser to the grid side of the coil and see that the circuit tunes satisfactorily.

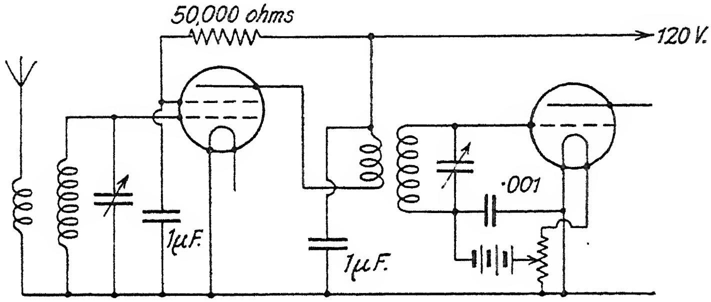

FIG. 30.—H.F. TRANSFORMER ARRANGEMENT WITH S.G. VALVE.

The strength will probably be poor, owing to the anode-bend rectifier. Then transfer the aerial directly (without the series condenser) to the terminal to which the anode of the valve is normally connected. (The H.F. valve must, of course, be disconnected all through this test.) This should give a similar signal unless the transformer is of the dual range variety, having only one primary for both wavebands. In this case the aerial capacity may tune with the primary winding to give a misleading effect. To avoid this difficulty, the test should be made on the long waves when the arrangement should behave satisfactorily. In any case some indication will probably be obtained as to whether the primary winding is working or not.

If any doubt is experienced on this score, as a result of such a test or for any other reason, the arrangement should be converted temporarily to a plain tuned-anode circuit, which may be done in the following manner: The connection from the anode of the H.F. valve is removed from the primary winding and is connected through a fairly large condenser, say ·01 μF, to the grid end of the tuning circuit. At the same time an H.F. choke, which must be of good quality, should be connected to the anode of the valve, the other end being taken to H.T.+, as shown in Fig. 31. The arrangement then becomes a parallel feed, the H.T. to the valve being supplied

through the H.F. choke, while the high-frequency currents are by-passed through the fixed condenser on to the tuning circuit. Provided the high-frequency choke used is really of a high grade, this method gives results as good as a simple tuned-anode circuit, and if this markedly improves the performance of the receiver, then there is either a fault or partial defect in the H.F. transformer. The transformer winding may be broken or incorrectly connected.

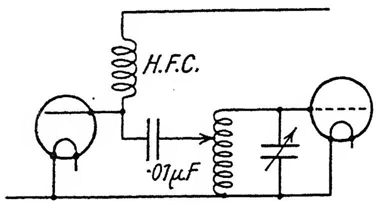

FIG. 31.—PARALLEL FEED WITH H.F. CIRCUIT.

The signal strength on a plain tuned-anode system is, of course, somewhat greater than the transformer-coupled arrangement as a rule. The transformer is designed to give a greater selectivity than can be obtained with the tuned anode, and for this reason a drop in signal strength may be experienced.

This method cannot be used as a general rule with neutralised circuits, as the circuit will become unstable if converted to a tuned anode arrangement.

The parallel feed arrangement just discussed may be found, in certain cases, to be an improvement over the original circuit, particularly in stabilising a circuit which is inclined to self-oscillation. The connection may be made either to the end of the coil or to any convenient tapping point, such an arrangement being sometimes referred to as the tuned grid system. The method is quite satisfactory, provided that a choke of really high quality is used. Some remarks on the subject of H.F. chokes were made in the last chapter (see page 58), and the choke for an H.F. feed should at least have the same characteristics as those outlined there. If the choke is of an inefficient type, then the amplification obtained from the stage will be reduced, since the impedance of the choke is in parallel with that of the tuned circuit, and if the resulting impedance is too low, only a small proportion of the total amplification on the valve is developed.

The Fig. 30 circuit has one other point of difference. The voltage on the screen is obtained from the full 120 volts through a breaking down resistance. The screen voltage should be

checked with a high resistance voltmeter or the resistance disconnected and the screen connected directly to the 80-volt tap on the battery, if there is any reason to suspect that the screened-grid valve itself is not functioning correctly.

INSTABILITY

We now come to consideration of the second form of trouble in high-frequency circuits, that of instability; here the difference between the screened-grid valve and the neutralised triode becomes apparent. The remarks so far may apply to all classes of circuit, but at this point we must consider the two classes of circuit separately.

With modern screened valve the anode-grid capacity is reduced to such a small value that under normal conditions the feed-back through this channel is insufficient to cause self-oscillation. The question as to whether the circuit is suitable for a valve in use is rather a question of design than testing, but the following data will be helpful in obtaining a rough indication.

The amplification obtainable from a screen-grid valve is given by the expression:

$$\text{Amplification} = \frac{L\mu}{L+CRrn^2}$$

where L = Inductance in μH, C = Capacity in μF, R = H.F. resistance in ohms, of tuned circuit.
r = Internal resistance of valve.
μ = Amplification factor of valve.
n = Step up ratio of transformer.
(= 1 if tuned anode is used.)

From the data of the circuit, therefore, the amplification can be obtained, and this may be compared with the figures in Table IV, which gives the maximum amplification permissible before self-oscillation sets in with the standard screen-grid valves of to-day. It should, perhaps, be pointed out that with the continuous improvement in valves which is always being made, this table may become obsolete before very long, and therefore the reader should obtain such data for himself in order to ensure that the information is up to date. The

formula given for the amplification, however, remains standard.[1]

TABLE IV

MAXIMUM PERMISSIBLE AMPLIFICATION FROM S.G. VALVES

Valve.	Resistance.	Amplification Factor.	Maximum Amplification.
Marconi S215 .	200,000	170	80
Mazda 215S.G .	270,000	300	150
Mullard PM12 .	230,000	200	80
Cossor 220SG .	200,000	200	90
Marconi S610 .	200,000	210	90
Mullard PM16 .	200,000	200	90
Marconi MS4 .	500,000	550	180
Mazda AC/SG .	600,000	1,200	230
Mullard S4V .	1,330,000	1,000	120

We can, however, assume that in the majority of cases the set has been correctly designed and is normally quite stable. If we find instability, therefore, it is due to the introduction of some difficulty which was not present in the original design. It is hardly necessary, of course, to point out that capacity coupling must be reduced to the absolute minimum. This is done by complete capacity shielding between the circuits. Except in the simplest cases partition screens are not sufficient. The screen should either be extended along the panel or along the baseboard, and preferably both, so that no trace of capacity coupling between the circuits can remain. Magnetic coupling also must be avoided as far as possible, but it is possible to arrange that such magnetic coupling as does exist is in a negative direction, and tends to make the circuit more stable.

[1] This formula only refers to the amplification obtained from the valve itself. The actual amplification over the whole stage is n times this value.

Stray Coupling

If the circuit is unstable, the first step is to suspect the presence of coupling between the circuits, and this is best checked by removing one circuit to a position some distance away. This may either be done by dismantling the particular portion of the circuit, or by connecting an equivalent and preferably identical arrangement some distance away, and connecting it to the appropriate points with long leads. A length of 10 or 12 ins. is usually sufficient to minimise any magnetic coupling which may exist.

For example, in the case shown in Fig. 29 we could remove the circuit to L1 C1 to a new position away from the second circuit L2 C2, and see whether the instability still remains. It is helpful to reverse the direction of the coil L1 or to rotate the coil if this is not practicable. If the removal of the tuned circuit in this manner or its orientation in some particular plane makes the circuit stable, then the difficulty is due to stray coupling, which must be obviated by an alteration of the disposition of the components, or by increasing the effectiveness of the screening or both.

The only way of obviating magnetic coupling completely is to enclose the coils in a copper or aluminium box. (Magnetic material such as iron should not be used for screening, as the losses are very heavy.) In general, however, it is not necessary to enclose the circuit completely, but a screen round three sides, of the form indicated in Fig. 32, is usually sufficient. The valve is preferably pushed through the screen as shown.

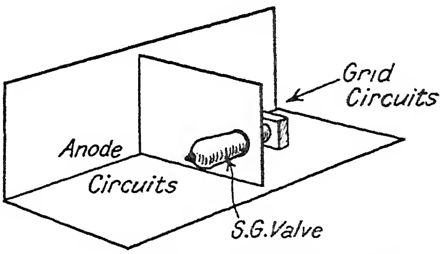

FIG. 32.—SIMPLE SCREENING SYSTEM.

If the instability is not due to stray coupling or to the use of too efficient tuned circuits, so that the amplification exceeds the critical value, the difficulty almost certainly arises from battery coupling, due to the presence of a common impedance in the battery circuit. This form of trouble can occur with any H.F. circuit whatever the type, and its location and cure

will, therefore, be deferred until the question of stability has been further discussed.

NEUTRALISED CIRCUITS

We still have to consider the type of H.F. circuit which utilises three electrode valves. While the screened-grid valve is rapidly ousting the triode for H.F. amplification, there are many occasions on which one encounters the older form of circuit. In this case the inter-electrode capacity is considerable and feedback, therefore, occurs as soon as the stage gain reaches a figure of 2 or 3. The most usual remedy is to adopt a circuit in which an equal and opposite feedback is arranged so that the valve capacity is neutralised. Other systems have been devised, but their application is limited and they cannot be discussed in detail here.

Neutralised circuits are liable to all the faults of the screened-grid circuit and the methods of testing are much the same. The majority of what has already been said, therefore, applies to triode circuits (unless the contrary has definitely been stated), while in addition there are certain other difficulties which are peculiar to neutralised systems, and we shall now proceed to the discussion of these points.

The principal fault is failure of the circuit to neutralise correctly, in which case the circuit oscillates continuously or in certain parts of the scale. The effect is due either to faulty design or to bad construction. Where a powerful signal is available (as from a local station) neutralising may be checked by the "silent point" method. Tune in the receiver approximately to the signal. Then switch off the H.F. filament, leaving the valve in position. The signal will probably still be heard faintly. Retune to maximum strength and then adjust the neutralising condenser until no signals are heard. It will be necessary to use telephones for this test.

With a good circuit a sharp, crisp and complete balance out is obtained, but a fairly well-defined minimum position will suffice. If the circuit is at fault, no minimum will be heard. The minimum point must be definite—there must be an increase on each side. A gradual decrease in strength over the whole range of adjustment is no use. If this effect is found it indicates that the neutralising condenser is incorrect in value. If the strength decreases continuously as the setting

of the neutralising condenser is reduced, the minimum is not low enough and another condenser must be used, having a smaller minimum. This is a common fault.

If the reverse is the case, the strength decreasing continuously as the neutralising condenser is increased, the capacity is not sufficiently great, though this is rarely found to be the case. Alternatively, or if there is no zero point at all, the neutralising circuit is connected the wrong way round. This can only occur with the type of circuit in which a separate neutralising winding is employed.

If this test cannot be applied, proceed as follows: Tune in the circuits towards the top of the wavelength scale (both H.F. and detector) with the reaction condenser at zero. If the circuit oscillates, reduce the H.T. voltage on the H.F. valve until the oscillation ceases. Next increase the reaction condenser until it does. Then readjust the neutralising condenser, and again set the reaction control so that the set is just oscillating. Find the position of the neutralising condenser at which the greatest amount of reaction is required to cause the set to oscillate. Carry out the test again at other points of the scale. The circuit should remain stable without any further alteration.

There should be a definite spot on the neutralising condenser for which the reaction required is a maximum. If the reaction demand increases continuously as the neutralising setting is reduced the minimum is not low enough. If the reverse is the case or if there is no definite indication, the neutralising condenser is not large enough or the neutralising winding is the wrong way round. Alternatively the oscillation is due to some other cause, for this test will not discriminate. The previous test is a better one if it can be used.

So far we have assumed only one stage. If there are more than one the circuit must be handled progressively. Start with the detector and the H.F. stage immediately preceding. Couple the aerial to the grid of the H.F. stage through a $\cdot 0001\ \mu F$ condenser, as usual, and treat the circuit as having a single stage of H.F. only. Carry out the tests just outlined, correcting any fault which may be found. Then transfer the aerial one stage farther back and confine the attention to the fresh circuit, thus brought into operation. Continue in this way until the whole circuit is in use.

Either the fault will be located or else evidence will be obtained that the instability is due to some other cause. If the neutralising appears to be correct and there is no serious stray coupling, the trouble is probably battery feedback, which is dealt with in the next section.

It has been assumed that the possibility of stray coupling has been eliminated already. The tests just outlined may give quite inconclusive results if this is not the case. Capacity coupling is permissible to some extent because it can be balanced out by an increase in the setting of the neutralising condenser, but magnetic coupling cannot be dealt with so easily. This form of trouble may be recognised by the fact that the setting of the neutralising condenser for stability has to be varied at different parts of the scale, showing that a true balance is not being obtained.

There are numerous other types of fault which may be experienced with neutralised circuits, such as parasitic oscillation, overlap, etc. Any more detailed discussion of the subject, however, is undesirable in the present instance owing to the tendency for this type of circuit to be replaced with arrangements using the screened-grid valve. Full details can be obtained in *The Book of the Neutrodyne*, in which I dealt with the subject fully some time ago.

BATTERY COUPLING

With the increasing H.F. amplification of to-day battery coupling is becoming troublesome in the H.F. stages. First of all we must know how this battery coupling can be set up, and here the reader should refer to page 44, where battery coupling in low-frequency amplifiers is discussed. It was pointed out there, that due to the passage of fluctuating currents from each of the valve circuits through a common high-tension battery, voltages were set up across the internal impedance of the battery, which in turn were transferred to portions of the circuit where undesirable reactions were set up.

In the specific case of a high-frequency amplifier, if the H.F. valve or valves and the detector valve are all supplied from a common H.T. battery, then small voltages set up by currents in the detector valve will be re-introduced into the H.F. circuits, and may conceivably be in such a direction as to cause self-oscillation. Alternatively they may be in the

reverse direction, causing the circuit to fail to deliver its true amplification.

One method of avoiding this is to isolate the circuit in the same way as is done in the low-frequency case. In this case, however, owing to the much higher frequency of the current, it is only necessary to use comparatively small resistances, and a circuit such as that shown in Fig. 33 will be quite effective in many cases. The condenser in use should be a mica-dielectric condenser, because the losses in a paper condenser at high frequency may be so large that the condenser does not act as an adequate by-pass, which would, of course, immediately defeat the object of the circuit.

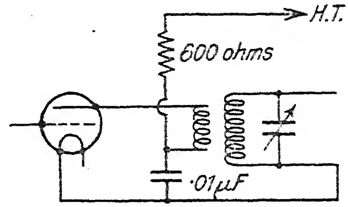

FIG. 33.—ILLUSTRATING H.F. FILTER.

An alternative method is to adopt the system shown in Fig. 31, where a high-frequency choke is used in place of a resistance. This method may be more effective than the resistance-filtered system, where the circuit having a very high amplification is being employed.

In many cases the introduction of a complete filter circuit in this manner is not necessary. The connection of a suitable by-pass condenser across the high-tension battery will often cure the trouble. This condenser, however, should be connected as near as possible to the actual point on the tuning circuit at which the high tension voltage is produced. Fig. 34 illustrates, for example, a typical layout, and the proper place for a condenser is across the point marked X and Y. The connection of a condenser across points marked B.C. would not be so good, because there is a considerable length of lead still left in the circuit, and there may possibly be a high resistance joint introducing difficulty. The trouble is more likely to be pronounced with very high frequencies (ultra-short waves), but the condenser by-pass should be connected as close as possible to the circuit in order to ensure the greatest margin of safety.

If battery coupling is suspected and the simple filter circuit of the type described does not overcome the difficulty,

the best plan is to use an entirely different battery for the high-frequency valve or valves. This battery should have its negative terminal common with that of the normal battery, but otherwise is completely isolated. No high-frequency current can then be introduced into the H.F. valve from the detector circuit through battery coupling. This will nearly always be found to cure the trouble if it is not due to some form of stray coupling between the circuits such as we have already assumed to be eliminated.

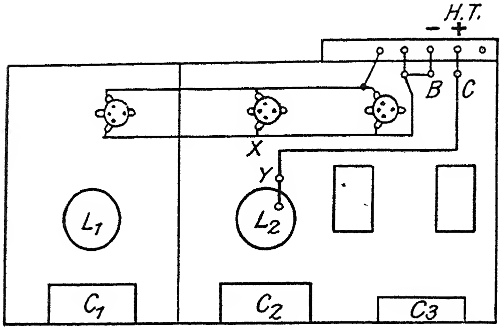

Fig. 34.—The By-pass Condenser should be Connected across X and Y.

If the connection of a separate battery in this manner overcomes the difficulty, whereas a filter circuit does not, then it is clear that the amount of energy sent back is very much greater than can be dealt with adequately by the simple filtering system. This usually points to the fact that high-frequency currents are being allowed to enter the low-frequency stages of the receiver, where they are to some extent amplified so that the feedback is occurring from one of the later valves in the set, not the detector valves, in consequence of which ordinary methods are unsatisfactory. Attention, therefore, may be turned with advantage to the precautions which are taken to cut out the high-frequency currents from the low-frequency stages. The precautions have already been discussed in Chapter IV, and reference should be made to the previous discussion, in order to find how best to carry out the improvements.

In many cases it is somewhat difficult to prevent battery feedback, and some circuits cannot be made to work on a run-down battery without the greatest difficulty. In such circumstances the simplest remedy is to discard the run-down battery, and to use a new one, but recourse should only be

had to this after the conventional remedies have been tried, because such a set is of little real service.

Where one is designing a receiver, such a course is not permissible, but if it is a matter of testing a receiver which has already been made, one is to some extent in the hands of the designer, and it may not be economical to adopt expensive methods in order to overcome battery feedback.

UNTUNED AMPLIFICATION

We now come to the consideration of the second form of H.F. amplification in which the circuits are either not tuned at all, or are arranged to give a general rather broad tune, somewhere within the waverange under consideration. This class of circuit is, of course, less efficient, but it saves one or more controls, and thus makes the set simpler in operation.

The general tests on a circuit of this nature are similar to those for a tuned circuit, except that one must go to work in a slightly different manner. We cannot work backwards from the detector in the usual manner, because the grid circuit is not tuned. We must adopt some other plan such as the connection of a temporary circuit across the input to the detector, the existing circuit being disconnected. For a simple test the preceding valves may be removed, but it is preferable to disconnect the existing detector circuit completely and replace it with the new circuit. This may consist of a simple coil tuned with a condenser, and signals may be obtained either from a buzzer or by connecting an aerial to the circuit. This will test out the detector and L.F. stages. We can then transfer the external tuning circuit one stage farther back, bringing into operation the H.F. stage immediately preceding the detector. If a definite gain in signal strength is not obtained, the inter-valve coupling circuit is faulty, assuming that all valves and holders are O.K. (This should have already been verified.)

Continuing in this manner we may bring into use all the H.F. stages (if there are more than one), finally replacing the temporary tuning circuit with the frame aerial (or other) tuning circuit incorporated in the set. The progress will be interrupted at the point where the fault occurs, and the location of the trouble is then a matter of attention to detail.

Definite information on the subject of untuned ampli-

fication is difficult to give as the circumstances differ in almost every instance. Considerable use of the system has been made in portable receivers using two stages of H.F. amplification, the inter-valve couplings being so called " aperiodic " transformers or chokes. The difficulty in design lies in the large waveband to be covered (200–2,000 metres), and the practice usually adopted is to use circuits which resonate in the lower waveband (200–600 metres), the amplification being maintained on the longer waves by virtue of the relatively high inductance of the chokes or transformers.

The only question which can legitimately be considered under the heading of fault-finding, is that of stability. It is usually found that if the chokes or transformers are identical the circuit is unstable; consequently the constants of the two H.F. circuits are made different so that the resonances occur at different points. If instability is found to exist, therefore, the chokes or transformers should be replaced with others having different characteristics.

Battery coupling is a very possible source of trouble with this class of circuit, and the remedies already outlined should be tried. Generally speaking, however, the difficulties with this form of circuit are either simple disconnections or short circuits, or else arise from poor design, in which case the remedies are outside the scope of this book. The adoption of the methods just outlined to test each stage from the detector backwards may lead to an improvement.

Choke coupling has been tried with the screened-grid valve, but the system usually fails owing to the difficulty of making the anode impedance sufficiently large, having regard to the high internal resistance of the valve. Instability is not likely to occur, and the faults which will arise in practice are, therefore, of a simple character and may be cured by the means already outlined.

SUMMARY

1. *Circuit unstable.*—If tuned amplification is used, investigate for stray coupling between stages. Isolate the defective stage as far as possible, and confine operations to this stage. If coupling is not excessive, make sure that amplification is within safe limits. If so, suspect battery coupling and adopt customary precautions.

If untuned amplification, try effect of replacing one or more of the chokes as trouble is probably due to resonance.

2. *Circuit behaves in poor manner.*—Convert system to simple detector followed by L.F. stages. Introduce H.F. stages one at a time, checking tuning in so doing. Introduce circuit step by step until faulty link is discovered.

CHAPTER VI

Mains Apparatus

In addition to the various forms of test already described, certain additional tests have to be applied where apparatus is designed for operation from power mains. Such apparatus may be designed to operate as a whole from the electric light supply, or it may be designed to supply the voltages to an existing receiver, in replacement of the customary batteries. The methods of testing are similar in the two cases, and we shall, therefore, consider in general the complete mains receiver, the mains unit or eliminator, as it is sometimes called, being a particular case of general proposition.

Electric light mains are of two kinds known as D.C. and A.C. respectively. In the D.C. variety, current flows continuously in one direction, whereas in the case of A.C., the current flows first in one direction and then in the other, alternating in this manner a large number of times per second. The total number of alternations or cycles per second is termed the frequency of supply, and in this country varies between 25 and 100 cycles per second according to the locality. In America the frequency is universally 60 cycles per second, while in due course the supply in this country will be standardised at a frequency of 50.

D.C. SUPPLY

We will consider the case of the direct current (D.C.) supply first. It is clear that we can utilise such a supply to provide the high voltages necessary for the anode circuit of the receiver in replacement of the customary H.T. battery. It is, of course, necessary to know which of the mains is the positive pole, and this may easily be determined by the aid of a pole finder. The use of this device, however, is seldom necessary, because the apparatus will only work when the

mains are connected the correct way round; if they are wrongly connected no results will be obtained. It is a simple matter of trial and error, reversing the plug in its socket if the set does not work the first time.

If it is desired for any reason to ascertain which is the + pole, a voltmeter may be connected across the mains, making sure, of course, that the range is such that the full voltage comes within the scale. The voltmeter, of course, will only read correctly if the + terminal is connected to the + pole. Otherwise it will read in the wrong direction.

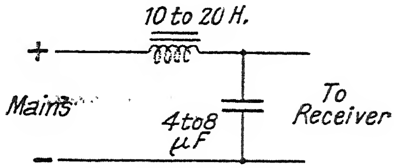

FIG. 35.—SIMPLE D.C. FILTER.

Generally speaking, the supply of current from an electric light main is such that it cannot be used to replace the H.T. battery without certain precautions. A direct current usually comprises a steady voltage together with a small alternating component, known as ripple. This ripple is produced by the generators at the power station, and usually has quite a high frequency, in the neighbourhood of 500 to 1,000 cycles per second. Before the supply can be used on a radio receiver, it is necessary to smooth out the ripple by the aid of a filter circuit such as that shown in Fig. 35. It should particularly be observed that in the D.C. case no condenser is required on the supply side of the filter. The generators at the power station supply unlimited power and no provision need be made to store up the energy. It is thus not necessary to have a reservoir condenser as in the case of A.C.

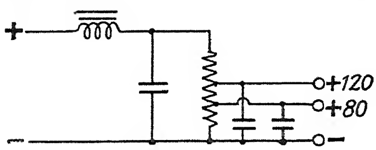

FIG. 36.—D.C. ELIMINATOR CIRCUIT.

A simple D.C. eliminator circuit is shown in Fig. 36. The voltage on the mains is usually in the neighbourhood of 200 volts, a value in excess of that required for the ordinary radio receiver. Some form of resistance is connected across the output, therefore, so that the voltage is cut down to a suitable value.

Motor-boating

A simple form of potentiometer, however, is liable to introduce serious back-coupling in the receiver. Back-coupling with a mains unit usually takes the form known as motor-boating. The oscillation set up is of a low frequency and gives a continuous " pop, pop, pop," sounding somewhat like the exhaust of a motor-boat. If this is experienced with a receiver operating from a mains unit of the type described, arrangements must be made to incorporate resistance-capacity filters in each H.T. lead, so that the audio-frequency currents can be prevented from flowing through the internal resistance of the mains unit. Alternatively, the arrangement of the mains unit may be slightly altered, as shown in Fig. 37, so that a common resistance in the H.T. circuit is avoided. One is, of course, still left with the common resistance of the smoothing choke, but this is usually small.

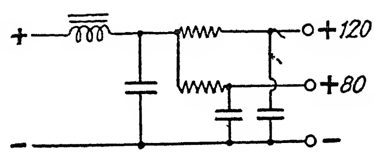

FIG. 37.—RE-ARRANGEMENT OF FIG. 36 TO PREVENT BACK-COUPLING.

Assuming that the instrument is developing some other form of trouble, the first step is to measure the voltage at the various points. The voltmeter must be of a high resistance type (at least 1,000 ohms per volt as already described), so that the current taken by the meter is negligible. The reason for this is that owing to the internal resistance of the mains unit, the voltage on the output terminals depends considerably upon the current that is being taken. As the current increases, the voltage falls due to the internal resistance of the choke and the remainder of the circuit, and so the voltage output is reduced.

Mains units, as a class have a bad regulation rendering them essentially different from batteries, which maintain the voltage irrespective of the load that is taken. It should always be seen that the unit is working under its actual operating conditions, i.e. that it is supplying the current which it is called upon to do in use. Check up the voltage from the mains through the eliminator up to the H.T. points of the receiver. It is easy to find if an undue voltage is being lost at any point, and so to ensure that the receiver is obtaining its proper supply of H.T. voltage.

Three-wire System Dangers

There is one point which must be emphasised strongly in connection with direct current mains. Most of the supply in this country is on what is known as the " three-wire system." Voltage is generated at 400 to 500 volts, a centre-tapped arrangement being provided on the generators. The centre point is connected to earth, so that we have two supplies of 200 or 250 volts, and the greatest difference of potential above or below earth is only 250 volts. This is done for reasons of safety, but the point is that on one side of the supply the earth is on the negative pole, while on the other side of the supply the earthed pole is the positive.

Now in a radio receiver we nearly always connect the H.T. — point to earth. At any rate the H.T. — point is connected to one pole of the L.T. supply, and the L.T. supply is earthed. The result is that if we endeavour to obtain H.T. voltage from power mains in which a positive pole is earthed, then if we connect this to a radio receiver, we shall obtain a direct short circuit which will blow the fuse. To obviate this, one must never connect a receiver to operate from the D.C. mains, directly to earth. A large condenser of 2 microfarads should be connected between the earth terminal on the receiver and the earth itself, and this will avoid the difficulties mentioned. This condenser must, of course, be sufficiently strong to withstand the D.C. voltage applied across it, and should preferably have been tested at a voltage at least twice that of the D.C. supply.

D.C. RECEIVERS

Apart from the use of an H.T. eliminator, it is possible to design a receiver to operate entirely from the D.C. supply. For this purpose, valves taking a filament current of 0·1 ampere are usually used, and the filament circuits are all connected in series. A large resistance is connected in series with the filaments and the mains, to reduce the current to the correct value of 100 milliamperes, and the voltage drop on this resistance is utilised in order to supply the necessary H.T. voltages.

A typical circuit is shown in Fig. 38. The valves are run with their filaments in series with each other, and with a high resistance, which incidentally must be capable of carrying

a current of 100 milliamps (actually a little more, as will be seen) without overheating. In conformity with what has already been said, the supply obtained from the mains must be smoothed, and to do this a large iron-cored choke, capable of carrying 100 milliamperes without saturation (see page 32) is necessary. This choke may have a resistance of several hundred ohms, and it should have an inductance when carrying its full load current of not less than 10 henries. A large

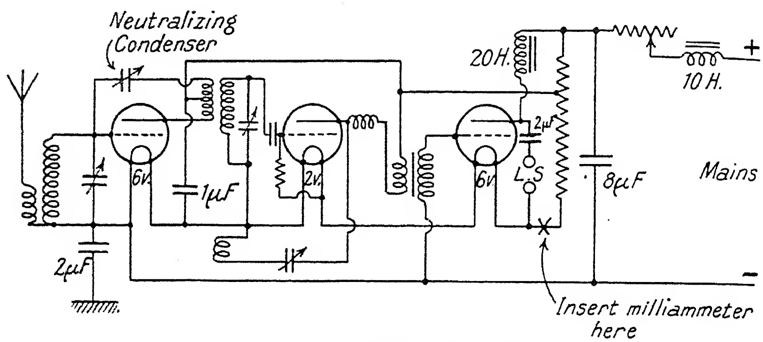

FIG. 38.—D.C. MAINS RECEIVER.

condenser is connected on the receiver side of the choke in accordance with customary practice.

When testing a receiver of this type, the first consideration is to see that the valves are obtaining their correct current. For this purpose a milliammeter capable of reading 100 milliamps should be placed in circuit at the point marked X in Fig. 38, i.e. at the junction between the breaking-down resistance and the valves. If the meter is inserted in the main lead, it will read the anode current as well as the filament current, and will thus give misleading results.

The next step is to check the valves. This cannot be done by the usual method of removing each valve in turn, because the filaments of the valves are all wired in series, and the removal of any valve breaks the whole circuit. Therefore it is necessary to break the anode circuit of each valve in turn at some convenient point, and to insert a milliammeter temporarily. If at any point no anode current is shown, this portion of the circuit requires further investigation. The valve should be removed and checked for emission in the

standard tester (see Appendix). If this is found to be correct, then the trouble lies in the circuit itself, and the customary tests should be applied in order to ensure that the circuit is continuous. The high resistance voltmeter will be of assistance here, for the voltage at each point can be measured. If there is a break in the circuit, then immediately after the break no voltage will be developed, and this will give an immediate clue to the difficulty.

Grid Bias

If no break is experienced in the circuit the grid bias arrangements should be examined. This point requires a little explanation for the arrangement as shown in Fig. 38 is peculiar. Since the filaments are all in series, the valve at one end of the circuit is at a different potential from the valve at the other end. We can arrange this difference in potential to be either positive or negative, as we require, according to the way we connect the mains, and the voltages can be so arranged that we can obtain automatic grid bias without difficulty. The circuit shown is a standard H.F., detector and L.F. arrangement. The H.F. valve is provided with zero bias, the return being taken to the negative leg of the H.F. filament. The detector valve is provided with a small positive bias, the detector leak being taken to the positive leg of the valve. This is in accordance with customary battery practice.

The low-frequency valve requires some 8 or 9 volts negative bias. We obtain this by using a 6-volt H.F. valve and 2-volt detector valve. The total voltage drop on these valves is thus 8 volts, so that the negative leg of the H.F. valve is 8 volts negative with respective to negative leg of L.F. valve. Therefore, we take the secondary of our transformer to the negative leg of the H.F. valve, and thus automatically obtain 8 volts bias.

Now if by any chance there is a wrong connection or a defective component in any of the portions of the circuit affecting this grid bias, we might conceivably obtain an incorrect voltage. Possibly, for example, the detector valve may be heavily negatively biassed, so that its anode current is reduced to zero. .If this is the case, the detector valve would take no anode current, and the circuit would be dead. Alterna-

tively, the power valve may have been incorrectly connected to have too little grid bias, in which case the anode current will be excessive, causing too big a voltage drop in the feed resistance. Therefore the bias should be checked, again using the high resistance voltmeter, in order to ensure that this portion of the circuit is functioning correctly.

These are the forms of additional test which would have to be applied to D.C.-driven receivers. The customary tests for tuning, H.F. and L.F. amplification and so on, must be applied in the manner already described in the previous chapters, the only difficulty being that no valve can be removed from its socket without making the whole circuit dead. Generally speaking the best method of procedure is to check through the voltages, starting from the mains and working downwards to see that the voltages that are applied to each valve are of the correct order. If any difficulty remains, it is usually due to some simple fault not connected with the mains drive, but due to some inherent defect in one of the components.

It should be emphasised that any testing carried out with a voltmeter on a mains set, should preferably be done with a couple of test prods, consisting of long ebonite rods having spikes at the end (see Chapter I). This avoids the risk of shock, in case one accidentally catches hold of live parts. The risk of shock with D.C. apparatus is not as great as with A.C. apparatus, but nevertheless no unneccessary risks should be taken.

Any other tests apart from actual measuring of voltages applied to the circuit should be made with receiver switched off, and the plug removed from its socket, so that the receiver is completely dead. There is then no risk of shock or of stray voltages damaging the instrument.

D.C. HUM

The most difficult problem to overcome in connection with D.C. apparatus is usually the hum produced in the receiver by the ripple already referred to. This is of a fairly high frequency, and can often be unpleasantly loud. As far as actual hum is introduced into the circuit, this can be eliminated by the use of filtering circuits of the type described. It is a fairly easy matter, therefore, to ensure that the current

actually supplied to the receiver is free from any ripple. If there is any doubt about this, the best plan is to add an additional filter circuit in front of that incorporated in the receiver. If this does not result in any appreciable improvement, as in the majority of cases it will not, the difficulty is due to some external source.

Particularly where the receiver has a high-frequency stage, hum is very liable to be picked up by direct induction between the circuit and the earthed pole of the main. The ripple is not solely at an audio frequency, for in many cases there is a small amount of high-frequency energy present in the supply, and this is modulated at a low-frequency by the ripple. It can be picked up by the H.F. portions of a receiver, which are very sensitive to stray induction, and will come right through to cause an unpleasant hum in the loud speaker. To ensure that no such high-frequency interference is coming in on the mains, a high-frequency choke should be inserted in the main supply lead. These chokes must have an inductance of 50,000 to 100,000 microhenries, should be wound in sections to minimise self-capacity, and must be wound with sufficiently heavy gauge wire to carry 100 milliamps without serious voltage drop or overheating. Such chokes are obtainable on the market, and the filter should be constructed by connecting one choke in each lead as shown in Fig. 39.

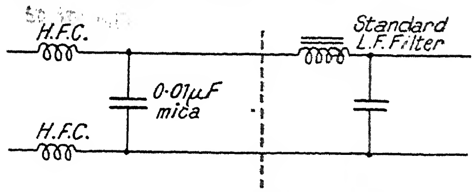

FIG. 39.—H.F. CHOKES ARE SOMETIMES NECESSARY IN D.C. MAINS.

If none of these remedies helps, then the difficulty will usually be found to be due to a difference of potential between the earthed pole of the mains and the earth wire of the receiver. More particularly is trouble experienced where the positive main is earthed, as this is a very prolific source of hum. The first procedure is to find out which of the mains is earthed, and this can be done by connecting a lamp, of the full supply voltage, between the earth and each of the mains in turn. When the lamp is connected to the main which is *not* earthed the lamp will light up, whereas with the earthed main no illumination should result, unless there is a fault on the system.

If the lamp lights when connected between the earth connection and *both* main leads, there is probably a fault on the system which should be reported to the supply company.

Under normal circumstances, however, one can find, without difficulty, which of the two poles is connected to earth, and having done this, a voltmeter should be connected between the earth and the earthed pole. There will usually be found to be a small difference in potential of 2 or 3 volts between these two, and if this potential is not large, the effect may be tried of connecting the earthed main definitely to earth. This, in many cases, will cure the hum, although in certain circuits it may make it worse. Alternatively, the two points may be connected together through a large condenser of 2 or 4 microfarads.

In some instances the hum persists even after all pre-

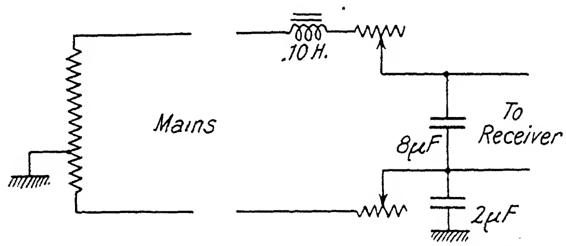

FIG. 40.—METHOD OF REDUCING HUM WITH D.C. MAINS.

cautions of this nature have been tried. Usually investigation in such cases will show the existence of an appreciable difference of potential between earth and the earthed pole. The only way to overcome this difficulty is to arrange matters in a sort of bridge formation as shown in Fig. 40. Here the left hand side of the figure represents the network of the mains themselves, and it will be seen that the actual earth point on this network is not at one end as it should be, but a small way up. If we are to obtain no hum we must arrange the right hand side of the network to be exactly similar, and this can only be done by moving the negative point of the receiver up the network to a small extent.

We have seen that it is necessary to drop the voltage by means of a series resistance, and that the voltage drop on part of this resistance is used for H.T. voltage. We very

rarely make use of the whole voltage, however, so that there is usually some spare resistance at the positive end of the set (see Fig. 38), which we can transfer to the negative end of the circuit if we wish. This has been done in the figure, the extent of the resistance being chosen to balance out the hum. As we increase the resistance in the negative side of the circuit, we must, of course, reduce the amount in the

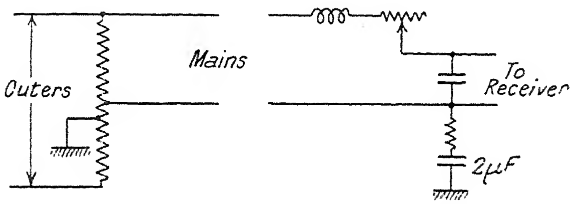

Fig. 41.—Alternative Method of Hum Prevention.

positive side, so that the total resistance in circuit remains the same, but we are effectively moving the earth point up the network, and by a process of trial and error a balance point can often be found at which the hum is reduced almost entirely.

If the earth point occurs on the other side of the zero point, as in Fig. 41, the position is much more difficult. A remedy can sometimes be obtained by earthing the set through a resistance, as shown in the figure.

A.C. SUPPLY

The greater percentage of electrical supply in this country is alternating (A.C.), and this is in many ways more convenient. In the first place it is distinctly safer in operation, for the receiver can be completely isolated from the mains, and therefore it is possible to ensure absolute safety from shock in use. The disadvantage of A.C. lies in the fact that it is necessary to rectify the current so that it flows in one direction only, and then to smooth out the resulting current so that it is substantially steady and free from variation.

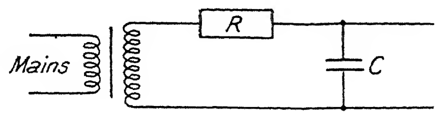

Fig. 42.—Single-wave Rectifying Circuit.

A brief description of the method of rectification and smoothing will be desirable. We obtain voltage from the supply through a transformer. This is an instrument which contains two windings on an iron core. The mains supply is connected across one winding and an alternating voltage is developed across the second winding, bearing a relation to the mains voltage depending upon the relative number of turns. We are thus able to step-up or step-down the voltage to any required extent, and this flexibility is one of the greatest advantages of alternating current operation.

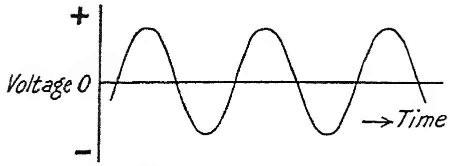

FIG. 43.—FORM OF ALTERNATING VOLTAGE.

Single Wave Rectification

Having obtained our output voltage, we apply this to a rectifier which is generally one of two forms. The simplest is shown in Fig. 42, and is known as a Single Wave Rectifier. It is either in the form of a valve or a metal or chemical combination, which has the property of passing the current only in one direction. When the voltage is in the right direction, the current is passed into the condenser C and charges it up. In the reverse direction no current flows, and the condenser remains charged. The next time the voltage is in its original direction, current will flow as soon as the voltage rises above the voltage to which the condenser has charged, and a further charge will flow to the condenser, resulting in a rise in voltage. This process will continue until the condenser has built up to a voltage equal to the maximum value of the alternating voltage.

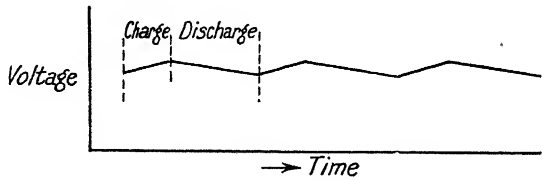

FIG. 44.—VARIATION OF VOLTAGE ON RESERVOIR CONDENSER.

It should be pointed out here that this value is approximately 1·4 times the rated value of the alternating voltage.

Alternating voltages or currents fluctuate in a regular and rhythmic manner, the variation of voltage with time usually being of the form shown in Fig. 43. If the voltage is varying from moment to moment in this manner, we clearly have difficulty in deciding what value the voltage shall be said to have. In order to render formulæ designed for D.C. operation applicable to alternating currents as far as possible, it has been decided that if the heating effect of two currents, one A.C. and the other D.C. are the same, the currents shall be rated as equivalent. This involves the use of a somewhat complex unit known as the root-mean-square value, which is arrived at in the following manner.

The heating effect of a current depends upon the square of the current. The heating effect of an alternating current thus depends upon the average or mean value of the square of the current at each successive instant, and we can easily determine the mean square. The equivalent current, therefore, is the square root of this current which is known as the root-mean-square, or the R.M.S. value. With the ordinary sine wave encountered in general practice this value is approximately 0·71 time the maximum value, whence we obtain the relationship that the maximum value of the voltage or current is 1·41 times the R.M.S. or rated value.

High Voltage

This little explanation is necessary in order to understand some of the effects which will happen. For example, if we have a transformer giving 100 volts on the secondary in a circuit such as that shown in Fig. 42, then if there is no load connected across the condenser we should find that the voltage across the condenser would rise to 140, and if we measured this with a meter taking no appreciable current, we should obtain a reading of 140. This tendency of the voltage to rise to a much higher value than normal when there is no load across the condenser is one

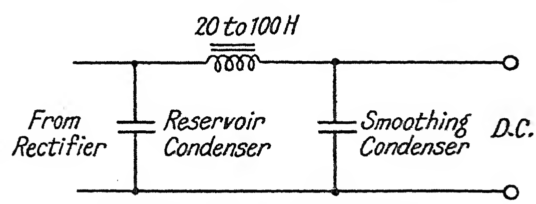

FIG. 45.—A.C. FILTERING CIRCUIT.

of the most important factors to be borne in mind when dealing with alternating current apparatus, for it is no pleasant experience to obtain a nasty shock of some 400 volts or so from apparatus supposed to be developing a little over 250 only.

Normally, however, we connect some form of load across the condenser and this draws off a certain amount of charge during the period when the rectifier is not passing any current. What actually happens in practice, therefore, is that the condenser is continually charging and discharging slightly, rather in the manner shown in Fig. 44, which will be seen to be equivalent to a steady voltage with a small alternating voltage superimposed.

This is unsuitable, as it stands, for radio work, just as D.C. supply is unsuitable, and we must connect a choke and condenser filter across the apparatus, so that our final circuit is of the form shown in Fig. 45. As in the previous instance the choke must be of such a character as to carry the necessary direct current without saturation, but the inductance must be considerably higher than in the corresponding D.C. case, because the fluctuations are at the same time more severe, and lower in frequency than with the D.C., and are thus not so easily filtered out.

Double Wave Rectification

The second form of rectification is known as the Double Wave type, and is illustrated in Fig. 46. Here the operation is the same except that two rectifiers are employed and the transformer is made with a double winding on the secondary, the two being connected together in the centre. Thus when the voltage is such as to give a positive potential on the top rectifier, current flows into the condenser in the ordinary manner. The next half cycle, however, the current is negative on the top rectifier, but is now positive on the bottom rectifier.

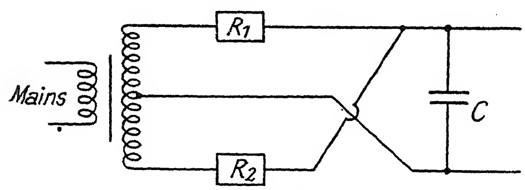

FIG. 46.—DOUBLE-WAVE RECTIFYING CIRCUIT.

Therefore currents flow into the condenser again by a different path, but in the same direction. Thus we utilise each half of the alternating voltage which gives us smoother working, and also a greater output voltage on the condenser.

This latter point will be obvious, for if we are taking a given amount of current from the condenser, and we supply a pulse of current, every $\frac{1}{50}$ of a second we shall obtain a certain equilibrium voltage on the condenser at which the current supplied in pulses equals the steady current taken out. If we feed our current in pulses 100 times per second (i.e. twice as much) we are putting in more than we take out, and the voltage will rise in consequence till we obtain an equilibrium condition once again.

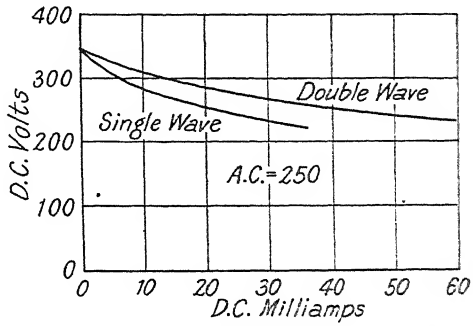

FIG. 47.—VOLTAGE ON RESERVOIR CONDENSER WITH TYPICAL VALVE RECTIFIERS.

As a guide to the order of affairs as may be expected, the curve shown in Fig. 47 indicates the voltage output from a representative rectifier of the Single Wave and Double Wave type.

Bridge Rectification

There is a third form of rectifier more commonly employed with metal or chemical rectifiers, which is known as the Bridge Arrangement. This is illustrated in Fig. 48, and it will be seen that four rectifier elements are used. When the top of the transformer winding is positive, the current flows through the path A.B. through the load, and then through the path D.C. The next half-cycle at the bottom end of the transformer winding is positive, the currents flow through the path C.B. through the load, and then through the path D.A. It will be observed that the reservoir condenser is charged in the same direction each half-cycle, so that we really have obtained a similar state of affairs to the Double Wave recti-

fication without having to employ a double voltage secondary with the centre tap, but at the expense of two further rectifying elements. The voltage on the reservoir condenser bears much the same relation to the voltage on the transformer secondary, as that for Double Wave rectification, in Fig. 47.

FAULTS ON A.C. ELIMINATORS

Having dealt with the broad principles of rectification in this manner, we can discuss the faults which are likely to arise in this portion of a mains apparatus. Strictly speaking, the first operation, following out our usual sequence of events, is to measure the voltage on the secondary of the transformer. This of course requires an A.C. voltmeter, and in some cases this voltage is of a dangerous value, exceeding 250 volts, so that the greatest care is necessary in this connection. It may be taken for granted, however, that a faulty transformer is not the most common defect in this class of apparatus, and we may perhaps make a more convenient starting point by measuring the voltage across the reservoir condenser (which is D.C.). For this purpose a high resistance voltmeter must be used, and it must, of course, be capable of reading the probable voltage well within its scale. If the normal output voltage of the eliminator is known, say 120 volts, then the reservoir condenser may read anything up to 250 volts. If it is not known, or in any case if there is any doubt, reference should be made to the curves just given in Fig. 47 in order to obtain some idea of the probable voltage.

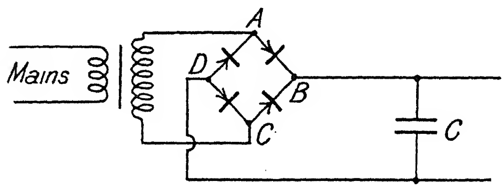

FIG. 48.—BRIDGE RECTIFYING CIRCUIT.

If the rectifier is functioning satisfactorily, the voltage on the condenser will be of the right order. The voltage should be measured with the apparatus in a working condition, i.e. supplying a load, as otherwise misleading results may be obtained.

If the voltage is found to be of the correct order, then the portion of the equipment up to the reservoir condenser is

satisfactory. If the voltage is higher than one would expect, this probably indicates a break somewhere later on in the circuit, so that the apparatus is not supplying its full load. This may be checked by continuing the voltage tests as described in a moment. If, on the other hand, the voltage is low or is zero, this again shows a defect.

Discharging the Condensers

The first defect to be tested for is a short circuit across the eliminator. The apparatus should be switched off, and the connections leading from the reservoir condenser to the remainder of the apparatus should be removed. Leave on those connections which come from the rectifier. Incidentally, as a precaution, the principal condensers in an eliminator or mains-driven receiver should always be short-circuited with a screw driver, after the current has been switched off, before any alteration is made. In the present instance where the voltage across the reservoir condenser is zero or very low, little danger is likely to result, but in other cases, particularly where one is looking for a fault, there is always a danger that one of the condensers will not have been discharged, and if one inadvertently catches hold of, or places a hand across the two terminals, a very unpleasant shock may result.

Therefore, get into the habit of placing a screw driver across the terminals of the reservoir condenser, and smoothing condensers, to discharge them, should they have any residual charge left. Grasp the screw driver by the handle, and place it in such a manner that the metal portion bridges the two terminals. If any charge is left, this will be discharged with a sharp spark, after which the circuit is safe to handle. This does not do any damage, although it is somewhat alarming at first. It must not, of course, be carried into operation while the circuit is still connected to the mains, but after the set has been switched off it is a very desirable precaution.

Reverting to our test, we have isolated all the remainder of the circuit, and we should now switch on the apparatus again, and once more test the voltage on the reservoir condenser. If it is now of a normal value (and as there is no load it will rise to the fullest possible value, i.e. 1·4 times the voltage on the secondary of the transformer), then the short circuit lies later on in the receiver, and we must examine the suc-

ceeding portions. It should be pointed out, however, that owing to the presence of this defect, the rectifier may have been damaged, and although it may behave satisfactorily on no load, it may still be found to give trouble when load is taken. After the fault has been remedied, therefore, it is desirable to check this point again, as will be seen later.

Let us assume, however, that the voltage is still low or non-existent. The next step is then to check the reservoir condenser. This may be done by disconnecting one side of the condenser, making sure that the circuit is otherwise unaltered. On switching on a voltage should now be developed across the output. The value will be reduced in intensity, but if any voltage now appears it indicates a faulty reservoir condenser. This should be replaced with a suitable equivalent. If on the other hand no voltage is obtained, even when the reservoir condenser is removed, it is probably the rectifier which is at fault.

This is more likely to be the case when the valve rectifiers are employed, as these will lose their emission under heavy overload. The rectifier should be tested or preferably replaced and a further test made of the voltage output. If no voltage is obtained now the transformer itself is faulty, and a test should be made with an A.C. voltmeter to confirm this, or to find which section of the transformer is faulty, in the case of a Double Wave arrangement. It may be found that one-half of the rectifier or the transformer is defective, in which case the instrument will only behave as a Single Wave rectifier, and the voltage on load will be correspondingly reduced. This will give, therefore, a partial working, but the results will not be up to what they should be. It is a matter of no difficulty to find which section is wrong for, on the removal of the rectifier from the faulty section, no alteration to the voltage will result, whereas the removal of the good rectifier will cause the voltage to fall to zero.

Smoothing Circuits

Reverting to the earlier test, if it is found that the fault lies beyond the rectifier, and that when the remainder of the circuit is removed the voltage appears, the smoothing and breaking down circuits must be gradually inserted a bit at a time, the voltage being measured at each point. The next

step, for example, will be to connect the smoothing choke and smoothing condenser across to the circuit. If the voltage is still present across both the condensers, this portion of the circuit is sound. If the voltage is present on the reservoir condenser, but not on the smoothing condenser, then there is a break in the smoothing choke. If the voltage across either condenser is zero, then there is clearly a short circuit across the smoothing condenser, and this condenser should either be removed and tested, or replaced by an equivalent condenser. We can continue in the same way to include each of the voltage tappings on the eliminator, bringing them in one at a time and noting whether the effects are normal or not. Any deviation from the normal expectation must be regarded as due to a fault until the reason is fully understood.

It should, perhaps, be pointed out that all the circuits in a mains unit of this type are interdependent. Suppose, for example, we have three output circuits, one normally giving 120 volts, and the other two giving 60 and 80 volts respectively. If we disconnect the 60 and 80 volt tappings, and connect only the 120 volt tapping with its appropriate load across it (i.e. connecting to the correct tapping on the receiver with which it is to be used) we shall find that the voltage on this tapping is more than 120. This is because we are not taking any load from the other two tappings, so that the total load on the eliminator is less than usual. This, therefore, must not be considered as an abnormality. If we introduce the 80 volts tapping we shall find that the voltage on the 120 volts tap will fall slightly due to the additional load, and when we bring in all three tappings, we should find that the voltage is approximately of the rated order.

The variation of voltage with load on an eliminator varies considerably with different kinds of instrument, and depends entirely upon the resistance of the smoothing choke and the size of the reservoir condenser. A cheap eliminator has what we call a bad regulation in that the voltage falls very rapidly as we increase the current taken from the instrument, whereas a more expensive eliminator has a more level characteristic.

L.T. Eliminators

L.T. eliminators are sometimes used, although to a limited extent. These are built on exactly the same lines as H.T.

eliminators, but the voltages dealt with are of a smaller order. Electrolytic condensers, having a capacity in the neighbourhood of 2,000 microfarads, are used for the reservoir and smoothing condensers, and the chokes are of relatively low resistance. Even so, the regulation is still bad and the voltage output varies considerably according to the current taken from the instrument. For this purpose a variable resistance is usually included in the instrument, together with a D.C. voltmeter, to indicate when the correct voltage is obtained. In adjusting any such instrument for correct operation on the receiver, it must always be used with the correct number of valves, and the rheostat must be controlled to give the right voltages on the valves. If any alteration is made to the number of valves in use, the voltage will be altered at once. A test for faults on such an eliminator follows out exactly the same principles as already outlined for the H.T. eliminator.

A.C. RECEIVERS

All-A.C. receivers are becoming increasingly common to-day, and for these instruments special valves are often employed in which the customary filament is replaced by an indirectly-heated-cathode type. These use a suitable cylinder or block of material coated with oxides which give off electrons profusely at a relatively low temperature. Running through the centre of this cathode is a small heater which is supplied with current from the A.C. mains at a voltage of 4 volts and a current of 1 ampere. In order to avoid hum, the cathode is usually connected to the centre point of the 4 volt winding on the mains transformer as this avoids any undesirable electrostatic effects. The cathode is made fairly massive so that it retains its heat and gives off a steady supply of electrons despite the fact that the heater is carrying a fluctuating current.

Receivers incorporating such valves may be tested in exactly the same way as ordinary receivers, the cathode being considered as the filament in each case. The only difficulty which is likely to occur is in the failure to obtain a connection between the cathode and the H.T. —. There is a tendency, particularly where receivers have been converted from battery working to A.C. working, for the heater to be considered as the filament, and for the H.T. — to be taken to the heater winding without any further connection with the cathode.

In this case the valve will obviously be unable to function correctly, for it is just the same as connecting up a battery circuit with no connection from H.T. — to the L.T. battery. Barring this point there is not likely to be any difficulty with A.C. valves.

In many cases the valve is directly heated by raw A.C. at a potential of 4 volts or more according to type. In such cases the H.T. — connection is taken to the centre point of the L.T. winding on the transformer. The circuit otherwise behaves as a battery-driven arrangement.

Free Grid Bias

A method of obtaining grid bias which is in very common use with the A.C. valves is the system known as free grid bias. With this arrangement the cathode of the valve is not directly connected to the H.T. — but is taken through a resistance. If we consider an isolated valve, such as that shown in Fig. 49 it will be seen that the anode current from the H.T. supply passes through the anode circuit, through the valve and then through this resistance to H.T. —. A voltage drop is, therefore, developed across this resistance, and as the H.T. — point is most negative in the circuit, the voltage drop on this resistance will be in the correct direction to provide grid bias. The grid circuit of the valve is, therefore, connected direct to H.T. —, thereby becoming a certain voltage negative with respect to the cathode. The value of the resistance is chosen such that the correct value of grid bias required is applied.

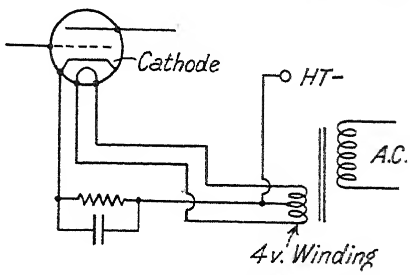

Fig. 49.—Illustrating Method of Obtaining "free" Grid Bias.

We only require a steady voltage to be developed across this resistance, however, and we do not wish fluctuating currents to set up any voltage in the grid circuit. A large by-pass condenser ranging from 1 microfarad to 4 microfarads depending upon the circuit is, therefore, connected across the grid bias resistance as shown in the figure. In any A.C.

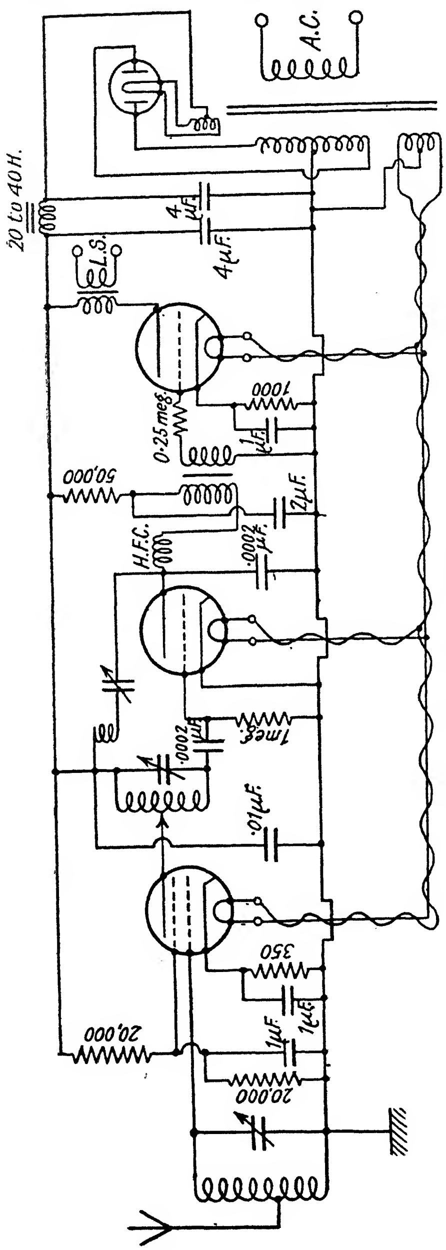

Fig. 50.—Typical A.C. Mains Receiver.

receiver this grid bias must thus be checked up on each valve in order to make sure that the valves are functioning under their correct conditions.

Fig. 50 shows a three valve A.C. receiver of modern design. A small negative grid bias is provided on the H.F. valve, and a larger bias on the L.F. valve. The grid leak in the detector valve is taken direct to the cathode, no grid bias being provided here. The examination of such a receiver for faults follows out the standard principles adopted with battery sets, and there is no need to outline the procedure in detail. If the fault is found to be due to the eliminator portion of the circuit supplying the H.T., then the tests must be applied as given earlier in this chapter. The grid bias on each valve should be measured with a high resistance voltmeter to see that it is of the right order, but otherwise the circuit, although apparently complex, requires no special treatment.

In some cases grid bias is not obtained by making use of this special arrangement. Resistance is included in the negative H.T. lead, and tappings are taken on this resistance at suitable points. Such an arrangement is shown in Fig. 51, the principal feature being that each lead has to be filtered to avoid coupling between the circuits.

This system differs from the previous case in one particular. With free grid bias the voltage applied to the grid circuit of each valve is controlled entirely by the anode current flowing through the said valve. Hence, if for any reason a valve ceases to function, no grid bias will be applied to that particular circuit. In this second case the grid bias is controlled by the total anode current flowing in the circuit so that if one valve is not functioning, the grid bias applied to the other valves will be reduced owing to the smaller voltage drop produced by the decreased anode current.

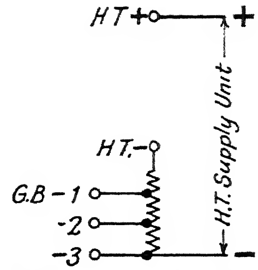

FIG. 51.—ALTERNATIVE METHOD OF OBTAINING GRID BIAS.

The filtering arrangements consist of a very high resistance, usually of the order of 1 megohm or more, with a by-pass condenser to earth as shown in Fig. 52. Since no grid current is actually flowing this high value of resistance is quite permissible, and acts as an effective choke against any audio frequency current trying to flow through the grid bias resistance. Such currents are immediately by-passed to earth by the condensers, thereby avoiding any coupling due to common resistance in the grid-lead which is liable to cause trouble in the same way as a common anode resistance.

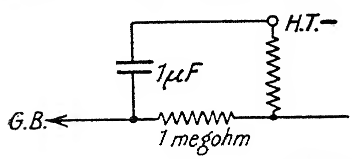

FIG. 52.—FILTERING ON GRID BIAS CIRCUIT TO AVOID BACK-COUPLING

Sometimes a combination of both methods is employed, an indirectly heated valve being used in the first stage, and a directly heated one in the second.

The point to remember in all these cases is that H.T.— is the most negative point in the circuit. The cathodes of the valves in the case of indirectly heated valves are thus

at a slightly positive potential, while in order to avoid hum the centre point of the 4 volt heater winding is connected direct to H.T. —. In the case of directly heated valves, the centre point of the heating winding is connected to H.T. — through the appropriate grid bias resistance—so that the filament again is at the necessary positive potential—while the grid circuit is connected to H.T. —, thereby obtaining the requisite negative voltage.

With directly heated valves the grid voltage must always exceed the theoretical value by an amount equal to half the peak value of the A.C. heating voltage. Otherwise during certain portions of the cycle the grid bias will be insufficient, and we shall obtain grid current. Thus if we have in the last stage of an amplifier a valve having a 4 volt filament which normally requires 9 volts grid bias, we must arrange this grid bias resistance to give an extra voltage of 2 × 1.4, or say 3 volts for safety. Hence our total bias voltage must be 12 volts.

The actual value of grid bias resistance is, of course, determined by dividing the voltage to be developed by the anode current flowing in the circuit, expressed in amperes. It is a useful rule to remember that a current of 1 milliampere flowing through 1,000 ohms causes a drop of 1 volt.

Provision of Centre Tap

It is sometimes required to make a temporary (or permanent) centre tap on a filament winding. This may be done by connecting a centre-tapped potentiometer across the winding in question. Such a potentiometer, however, must be of low resistance (20 to 30 ohms only), as otherwise hum may be introduced into the circuit.

A.C. HUM

The problem of hum with A.C. receivers is in some respects less severe than with D.C. and in others more so. The very troublesome induction hum due to the positive earth or imperfectly earthed main which was mentioned in the D.C. case does not arise. Direct induction can occur, however, in the receiver itself—between the mains transformer and certain of the components. This is more particularly the case where the transformer is too small for its work so that the iron circuit

is working at an abnormally high flux density with consequent large leakage flux. The remedy is to shroud the transformer or move it farther away or dispose the components in some other manner.

Hum due to imperfect smoothing of the rectified A.C. is fairly easy to detect. The earlier stages require more smoothing, while the output stage will tolerate several volts A.C. ripple without producing serious hum. Introduce extra smoothing circuits consisting of a choke and condenser into each anode lead in turn until a case is found where a marked diminution in hum is obtained. This is the faulty link. Alternatively, increasing the smoothing capacity by adding further condensers in parallel with existing ones will give a similar though less definite indication.

A process of elimination must be adopted as always, but there is one important point to be remembered, namely, that the various circuits often affect one another to some extent. For example, a two valve A.C. set having a directly heated output valve with an indirectly heated detector will often hum when switched on, becoming quiet in a few seconds after the detector heater has warmed up. The load of the detector on the L.F. transformer stabilises the circuit.

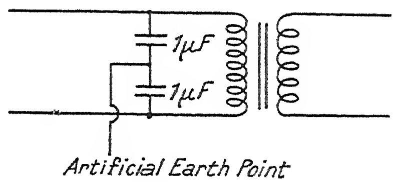

FIG. 53.—FORM OF ARTIFICIAL EARTH OFTEN USEFUL WITH A.C. SETS.

Clearly, if the detector valve is removed the hum will become worse, and if we wish to isolate the detector circuit we must adopt some other method.

Earthing makes a considerable difference to the hum. Failing a good earth, all zero potential points should be connected to H.T.—, including all the cores of the chokes, transformers, etc. If this point can be connected to earth as well, so much the better. A form of artificial earth which is often helpful is that shown in Fig. 53. Two 1 microfarad condensers are connected across the A.C. supply, and the centre point is treated as an earth.

CHAPTER VII

Special Tests

In the foregoing chapter we have discussed the general routine of set testing in all the different departments. There are one or two special cases which require to be elaborated in order to appreciate how the principles already outlined can best be applied. It is proposed to deal with these in the present chapter.

SHORT WAVE SETS

Perhaps the most important of these special cases is that of receivers designed for operation at very high frequencies, so that the short wavelengths from 10 to 100 metres can be received satisfactorily. It is often supposed that reception on these wavelengths is difficult, but in practice this is not the case, for a receiver behaves in exactly the same manner on short wavelengths as for the ordinary broadcast wavelength, always provided that one makes allowance for the very much higher frequency. In this light certain effects which are negligible on broadcast wavelengths become of considerable importance in short wave reception.

Let us take, for example, one of the most common troubles experienced with this class of set, namely failure to oscillate. The circuit employed for producing oscillation in a typical short wave receiver is shown in Fig. 54. It will be seen to be similar in character to a standard broadcast receiver, the differences being in the values of its components. We have a tuned grid circuit, with a reaction coil coupled thereto, the amount of energy supplied from the anode into this reaction circuit being controlled with a variable condenser.

Now common experience shows us that on the broadcast band the number of reaction turns required to produce oscillation satisfactorily is around 50 per cent. of the number of

turns on the tuned circuit. In some cases we can do with less than this, and up to a point the smaller the number of reaction turns the better, because in such a case the possible influence of the reaction circuit on the tuning is minimised. Exactly the same condition of affairs applies in a short-wave set. The reaction turns should be anything from one-third to one-half of the tuned turns. They must, of course, be coupled in the right direction. More turns than this should not be used because the tuning range will be seriously affected, and the same rule applies as in ordinary broadcast practice, namely, that the smaller the number of reaction turns the better. Therefore, if the circuit conforms to this specification, look elsewhere for the trouble. Do not waste time endeavouring to increase the number of reaction turns.

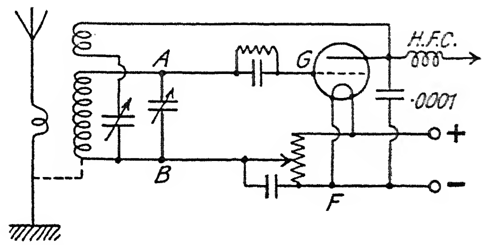

FIG. 54.—TYPICAL SHORT WAVE CIRCUIT.

Another fallacy which is very prevalent is that low-loss tuning arrangements are essential. Whether this is the case or not depends on what is meant by low-loss. The losses which are of importance at very high frequencies are the conductor losses and eddy-current losses. The dielectric losses are of secondary importance, in fact, less important than they are on normal broadcast wavelengths. Therefore, if one finds the coils wound on ordinary solid tube, do not immediately rush to the conclusion that the losses are too heavy. The important factors are that the turns on the coil should be spaced apart by a distance equal to several times the diameter of the wire, and the wire should be copper or silver-plated copper—not nickeled or tinned.

By-Pass Arrangements

These points have been dwelt upon, because considerable time can be wasted in altering a circuit unnecessarily. The production of oscillation at short wavelengths is a relatively simple matter, and is controlled by far more ordinary causes

than one would suppose. Perhaps the most common source of trouble is the failure to provide an adequate path for the high-frequency currents after they leave the tuned circuit. Let us return once again to Fig. 54. In the grid circuit we have a potentiometer across the filament in order to obtain the best rectifying point, so that the reaction shall be smooth. A high-frequency current has to pass from the tuned circuit to the grid and filament of the valve along the two feeder lines AG and BF. It will be clear that in the line BF we have the resistance of part of the potentiometer, and this may offer sufficient impedance to the current to prevent the circuit from oscillating. A condenser should, therefore, be placed between the point B and the negative filament lead as shown. A condenser from the anode of the valve to L.T. — will again assist the detector to function properly, and will often cause the circuit to oscillate rather than prevent it.

Fig. 55 shows a tuned-anode circuit; although the high-frequency amplification on these wavelengths is usually small, the advantages gained from a high-frequency stage are often of value. Reaction in this case is applied from the detector valve on to the tuned-anode circuit, and it will be found imperative to connect a by-pass condenser across from the point X to L.T. —. It may be that the particular set already has a large condenser across the H.T. battery, but as explained in a previous instance, this will not be sufficient. The inductance of the lead running from the tuned circuit to the H.T. terminal will often be sufficient to prevent the circuit from oscillating, and the by-pass condenser must be connected from the tuned circuit itself to the negative side of the filament of the detector valve, using as short a lead as possible.

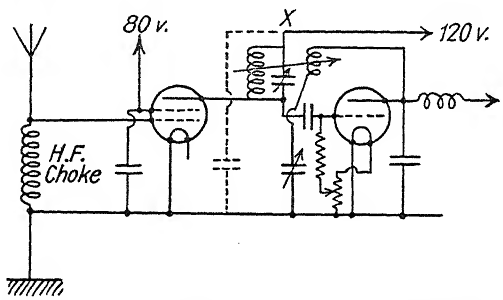

Fig. 55.—Short Wave Circuit with H.F. Valve.

These two instances will serve to exemplify the differences

in procedure arising from the very high frequencies, and these remarks, coupled with what has been said in previous chapters dealing with tuning and H.F. amplifying circuits, should enable the reader to overcome any difficulties which may arise. Make sure that the high-frequency energy has an easy path, remembering that the inductance of a short length of lead is quite appreciable at these high frequencies. As a matter of fact a length of wire 10 centimetres (4 ins.) long and 1 millimetre diameter has an inductance of 0·1 μH, and this at a wavelength of 20 metres has an impedance of approximately 10 ohms, so that although its high-frequency resistance is a small fraction of an ohm, such a wire would present considerable impedance to the high frequencies with which we are dealing.

Tuning Difficulties

This leads to the second of the difficulties usually encountered in short wave practice, that of obtaining satisfactory tuning. This point is also wrapped up with the production of oscillation, for in certain cases a badly conceived layout will not only give a poor tuning range, but will prevent the circuit from oscillating.

Perhaps the principal feature of short-wave reception is the very small inductances which have to be employed. In order to tune to resonance with a condenser of ·0001 microfarads, at a frequency of 15 million cycles per second (20 metres) we require an inductance of 1·2 microhenries only. This is obtained by using two or three turns of wire on a relatively small diameter former, the turns being well separated in order to minimise conductor loss as was mentioned previously. We have already shown that a length of 4 ins. (10 centimetres) of wire has an inductance of 0·1 microhenry, which is nearly 10 per cent. of the total inductance of the circuit. It is quite possible to arrange the coil some distance away from the tuning condenser, so that leads considerably in excess of 4 ins. have to be used. This might easily increase the total inductance in the circuit so much that the circuit would not tune down to the wavelength for which it was intended.

So far we have only considered the inductance of a straight wire, but if we arrange our wires so that they enclose an area the inductance is increased. In practice it is quite an easy

matter to double the inductance by bad wiring, so that a circuit intended to tune say 15 metres would actually refuse to tune below about 25 metres.

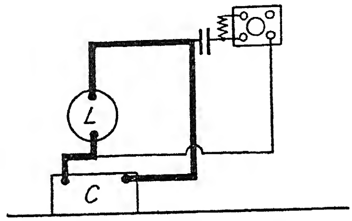

FIG. 56.—EXAMPLE OF BAD CIRCUIT WIRING.

Such a trouble is illustrated in Fig. 56 where the oft quoted advice to keep the grid leads short has been followed out. The lead between the coil and the grid of the valve is undoubtedly very short, but actually the tuned circuit does not only consist of the coil and the condenser, for the closed loop shown in heavy line is also within the tuned circuit, and probably has an inductance comparable with that of the coil itself.

The circuit correctly arranged is shown in Fig. 57, where the leads between the coil and the tuning condenser are as short as possible and are run relatively close together (not less than ½ in. apart, in order to avoid excessive capacity), while relatively long leads are taken from the tuned circuit to the grid. Such practice is preferable for although long leads to the grid may cause a small loss in voltage, they do not affect the tuning properties of the circuit.

Hence, if the circuit does not tune down to the nominal wavelength, therefore this is the first thing to suspect. If the coil has the correct inductance, then with a proper layout of the circuit, it must tune to its nominal minimum without difficulty. The valve, valve holder, and variable condenser all combine with the wiring to give a minimum capacity in the neighbourhood of 50 microfarads; this capacity must be taken into account when calculating the minimum wavelength to which the circuit will tune.

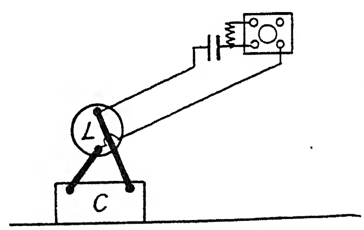

FIG. 57.—THE CORRECT WAY TO WIRE A SHORT WAVE CIRCUIT.

The possibility of bad wiring preventing oscillation was mentioned earlier. The reason for this will now be clear.

We couple our reaction coil to the tuning coil in the circuit. We have seen that it is not desirable to increase the reaction turns to a value much in excess of half the number of turns on the tuning coil. Clearly, if the circuit wiring is so constructed as to introduce an extra inductance of the same order as that of the tuning coil, our reaction winding is no longer coupled to the whole circuit, but only to a part thereof. Under such circumstances reaction may be difficult to obtain. On re-wiring the circuit as already discussed, the reaction coil will couple to the whole inductance in circuit, and this will probably be found to cure the difficulty.

The possibility of the reaction coil affecting the tune has also been referred to. If the number of turns on the reaction coil is excessive, it will prevent the circuit from tuning to its proper minimum. This more particularly is the case where, owing to bad construction or insufficient by-passing in the rest of the circuit a large amount of reaction capacity has to be employed in order to make the circuit oscillate.

Suppose, for example, that we have 4-turn coil tuned with a condenser of 100 $\mu\mu$F, including valve and circuit capacity. Let us assume that the reaction coil has 2 turns, but that owing to bad construction the reaction condenser has to be increased to 300 $\mu\mu$F (·0003 μF) before the circuit oscillates. Now the tune of this reaction circuit is distinctly higher than that of the grid circuit, and it will be found impossible to tune the circuit below the wavelength at which the reaction circuit resonates.

Therefore, not only must the reaction turns be kept small, but the circuits must be carefully constructed so that only a relatively small value of reaction condenser is necessary. Various ways of making the circuit oscillate easily have already been discussed, and attention to these points will usually result in the circuit behaving in a satisfactory manner. Many of the points discussed have been largely matters of design, but the peculiar difficulties encountered with short wave sets usually arise from defective design or construction.

Threshold Howling

A form of difficulty often experienced in short wave receivers is known as "threshold howling." The successful operation of a short wave set depends largely upon a very

smooth and progressive reaction control. Satisfactory amplification at very high frequencies is still a matter of difficulty, and the most popular forms of circuit, therefore, are those employing a very highly sensitive and nicely adjusted detector circuit. It may be found that just when the detector is on the threshold of oscillation, it sets up an unpleasant growl or shriek which entirely blots out the reception. This unpleasant state of affairs is due to a change in the constants of the circuit which takes place immediately the set is made to oscillate. The effect of this change momentarily pulls the set out of oscillation until conditions have readjusted themselves when it will commence to oscillate again. Such a trigger action, equivalent to the mechanical operation of an electric bell, causes a squeal or growl having a frequency equal to the number of times per second the set falls in and out of oscillation.

A simple remedy, which is usually effective, is to introduce a resistance in the anode circuit of the detector valve. A value of 10,000 ohms is usually sufficient. With a grid detector the anode current falls when the circuit oscillates, and this causes a decreased voltage drop on the resistance. Hence the anode voltage on the valve rises, and holds the circuit in oscillation. While we do not wish to use the circuit in an oscillating condition (unless receiving C.W., when the difficulty does not arise), this arrangement is inherently stable and we can creep right up to the oscillating point without difficulty.

Another remedy is to connect a $\frac{1}{4}$ megohm resistance across the secondary of the L.F. transformer. Threshold howling, by the way, rarely occurs with a resistance-coupled stage, due to the fact just stated that a circuit with resistance in the anode lead is inherently stable.

Flat Spots

In tuning a short wave receiver, one often encounters effects known variously as "flat spots," "dead spots," "holes," "beetles," etc. The circuit refuses to oscillate, or requires a considerable increase in the reaction setting, at certain points of the dial. This is due to some absorption effect which must be located and removed if the trouble is to be overcome.

The most prolific source of this absorption is the aerial

circuit. It may be that the wavelength being received coincides with a harmonic of the natural wavelength of the aerial. The difficulty is removed by altering the natural wavelength of the aerial by inserting a small series condenser. A value of ·0001 μF is quite sufficient. The difficulty is more pronounced with long aerials and better reception all round is obtainable on short wavelengths with a small aerial.

The introduction of a condenser in this manner may introduce a flat spot on some other wavelength. In some cases it is possible to arrange matters so that the aerial does not interfere with reception at all, but if this desirable state of affairs cannot be attained, arrangements must be made for inserting or removing the fixed condenser at will.

If the aerial circuit is not found to be the cause of the trouble, then one must examine the receiver for possible closed circuits. It may be that certain portions of the L.F. stages, for example, constitute a completely closed inductance of relatively large dimensions, and this may resonate on some wavelength within the tuning range, and hence absorb energy. Particularly in a case where one is using some sort of framework or chassis this effect must be looked for. There is a possibility that some nearby circuit is causing an absorption effect, although this is rather rare.

Before leaving the subject of short wave tests, some reference should be made to the method employed for checking the tuning with this class of receiver. An ordinary buzzer wavemeter is not suitable, and an absorption wavemeter is usually employed. This consists of a simple tuning circuit comprising a coil tuned with a variable condenser, the wavelength of the combination being determined according to the reading on the condenser dial. This wavemeter is brought near the circuit under test (within two or three inches) and the condenser is gradually rotated until the absorption takes place.

The absorption is best observed by allowing the receiver circuit to oscillate gently. When the wavemeter comes into tune, the circuit will cease to oscillate over a few degrees of the wavemeter dial, and will recommence to oscillate as soon as the wavemeter is mistuned again or removed. From the reading on the wavemeter the wavelength of the circuit can then be determined. The circuit should be only just oscillating, as otherwise the wavemeter will have to be placed too close

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to the circuit in order to stop the oscillation, and this leads to inaccuracies. Secondly, the wavelength of the circuit in the oscillating and non-oscillating condition is not the same unless the circuit is only just oscillating.

SUPERHETERODYNE RECEIVERS

Another form of receiver which requires special mention is the superheterodyne. This form of circuit is not very common in this country, but has some advantages which may make for its popularity under special conditions. It consists of an arrangement in which an oscillating detector is employed, so adjusted that the beats between the carrier wave of the incoming signal and the local oscillation are not produced at an audible frequency, but at some relatively low radio frequency. This current is then passed through what is known as an intermediate frequency amplifier, which is tuned to the particular wavelength after which the signals are rectified in the customary manner and amplified at low frequency if necessary. The advantage of the method, of course, is that the tune of the intermediate frequency amplifier remains fixed and can be made very sharp, thus enabling high and selective amplification to be combined with simplicity of operation.

Now apart from the general tests which have already been discussed, there are obviously two special forms of test which apply in this instance. The first of these is on the intermediate-frequency amplifier itself. First of all this must be tuned correctly throughout. The checking of this point is a somewhat difficult business, which is best done by plotting a resonance curve in the same way as is discussed in Chapter X.

We can usually assume, however, that this is not the fault, for in the majority of cases the circuits are sufficiently well tuned to give good amplification and selectivity.

One is more likely to encounter a definite fault. Testing for this is a matter of proceeding through the amplifier stage by stage, applying the customary tests for continuity and so forth. If a buzzer wavemeter can be arranged to operate at the frequency to which the intermediate stages are tuned, then of course one's process through the set is facilitated, for it is possible to obtain a rough check on the amplification of each stage, and to see whether any one stage is not up to standard.

A more common form of difficulty is that of self-oscillation

in the intermediate stages. The intermediate frequency amplifier must be constructed, of course, to give the greatest amplification possible with stability. In order to do this, the arrangement is often allowed to be unstable at its most efficient point, and is restrained from oscillating by the application of a small positive bias on the grids of the amplifying valves. It may be that one particular stage is too lively, and additional restraint must be placed upon it.

The symptoms of oscillation in the intermediate stages are that nothing but whistles is heard on rotating the tuner and oscillator dials. Moreover, the customary oscillation whistle is obtained on the carrier wave of one's local stations. This is not present when the superheterodyne is working properly. In order to find which is the offending valve a milliammeter should be inserted in each of the anode circuits of the intermediate frequency stages. The valve which is oscillating will be found to take considerably more anode current than the remainder. Having found the offending valve, either a less efficient valve must be employed or some deliberate damping must be introduced into the circuit. Alternatively, if one is really experienced, neutralising may be attempted.

The First Detector

Attention should next be turned to the first detector and the oscillator. For satisfactory operation the first detector must tune satisfactorily to signals on the normal wavelength. This is easily checked by using a pair of telephones in the anode circuit of the detector and tuning in with a buzzer wavemeter. Owing to the sensitivity of this class of circuit a frame aerial is nearly always used. The wavemeter should be placed near the frame and set in operation when signals should be clearly received and sharply tuned.

Next we must ensure satisfactory oscillation is being produced to combine with the incoming signal and produce the inaudible (supersonic) beats. The frequency of the oscillator is near to that of the incoming signal, being such that the difference in frequency between the local oscillation and the incoming signal is equal to the intermediate frequency. If one is working with an intermediate frequency of 30 kilocycles (10,000 metres) and wishes to receive a frequency of

830 kilocycles (360 metres) the oscillator must be adjusted to 800 or 860 kilocycles. Thus the range of oscillation required is similar to the tuning range of the frame aerial circuit.

The oscillation may be produced by a separate valve, or by allowing the detector valve to oscillate. In either case one can check whether the circuit is oscillating or not by inserting a milliammeter in the anode circuit. If the circuit is oscillating there will be a large change in current if one places a finger on the grid of the valve, or upon the grid side of the variable condenser. Alternatively, a pair of telephones may be used in place of a milliammeter, a loud "plonk" being heard if the set is oscillating, and only a soft "plop" if the reverse is the case.

If the circuit is not oscillating it means that the reaction winding on the oscillator is either not functioning (disconnected or faulty) or that the anode circuit of the valve is insufficiently by-passed. Since both the oscillation and the incoming signal are at the customary broadcast frequencies, adequate returns to earth must be provided for the currents after they have done their work. In the anode circuit of the first detector valve there is a tuned circuit which is adjusted to resonate at the beat frequency—a fairly long wavelength (low frequency) as we have already seen. One must, however, provide a separate path for the high-frequency currents which are no longer required, having served their purpose.

A by-pass condenser must thus be connected either directly from the anode of the valve or immediately after the first intermediate tuned circuit, if the arrangement is to work efficiently. Failure to incorporate these by-pass condensers may cause the oscillator circuit to cease to function in which case the whole circuit is dead.

These are the general points in a superheterodyne receiver which require special consideration. There are other difficulties which arise, such as the use of insufficient coupling between the oscillator and the detector, which gives weak signal strength; or the use of too tight a coupling which causes the two circuits to interact seriously, one pulling the other out of tune with a "click." Such matters, however, are details of design rather than fault-finding, and cannot be considered further in the present instance.

CHAPTER VIII

Some Curious Faults

In previous chapters we have seen that "method" is an all important factor in tracing faults. Not only does this make the process more rapid, but it is a fascinating exercise for the brain to work on logical lines, for by a process of elimination we are bound to find the solution. Most of us enjoy detective fiction merely because exercising the mind in the tracing of clues is a pleasant occupation. If we learn to do this also in tracing wireless troubles, much of the tediousness will disappear.

The present chapter deals with some rather curious faults experienced in the course of routine work. The troubles may justly be termed curious, in that they were not discovered merely by conducting the simple tests already described, but required additional thought, guided by the clues obtained after making the normal measurements.

Grid Leak Troubles

An interesting case was that of a receiver which developed a curious hum. There was no simple reason for this trouble, since H.T. batteries and L.T. accumulators were being used. The quality of reproduction did not appear to suffer, but it was noticed that when going into oscillation the reaction was unusually smooth; even when the reaction condenser was suddenly increased the set slid into oscillation without any "plop." This effect supplied the clue, for a low value of grid leak very often causes the reaction to become less smooth. Conversely reaction becomes smoother as the grid leak increases in value. On substituting a new leak the hum completely disappeared. Afterwards it was found that the old leak had suddenly increased in value from 2 megohms to 12

megohms, causing the grid circuit of the detector valve to pick up hum from the A.C. mains in the laboratory.

Whilst on the question of grid leaks reference may be made to another rather baffling fault, taking the form of an elusive loose contact. This type of fault is very annoying. Loud crackles emanate from the loud speaker whenever anyone moves across the room. Some time was spent in going over all connections, hoping to find a loose contact or unsoldered lead. Finally the trouble was traced to the grid leak being a loose fit in the holder, although in appearance the surrounding clips appeared to grip the leak securely.

Partial Breakdowns

A curious fault developed in an amplifier resulting in a regular series of loud clicks, something like the ticking of a clock but considerably faster. First of all I examined the grid leak, expecting that this was faulty ; the trouble, however, was not here. The noise was similar to that caused by rain falling on a badly insulated aerial lead-in wire ; for this reason various components were tested with a Megger[1] in the hope of finding a leak from the terminals of a large fixed condenser to its metal casing or some such fault. The diagnosis was partly correct, for it was discovered that a low-frequency choke in the amplifier was short circuiting to frame. On replacing the choke the trouble entirely disappeared.

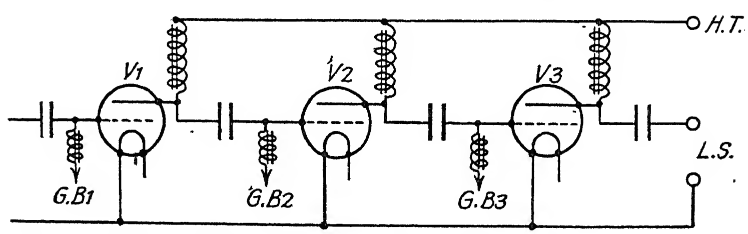

FIG. 58.—A DUAL-IMPEDANCE CIRCUIT WHICH GAVE TROUBLE ON ONE OCCASION.

Loose or bad contacts are responsible for quite a number of faults in practice. On one occasion an annoying crackling was experienced in a receiver employing two stages of dual-impedance coupling. The circuit is shown in skeleton in

[1] A device for measuring insulation.

Fig. 58. Following the usual systematic methods it was found that the removal of the first valve V_1 in the amplifier caused the crackling to cease. Therefore the fault was either, apparently, in the anode circuit of this valve or in some portion of the circuit prior to this point. The grid circuit of the valve was removed, and a short circuit was connected between the grid and filament. On re-inserting the valve the crackling was still present, indicating that the fault was not before the valve but was taking place in the anode circuit.

Careful tests were made on the anode circuit, and indeed the anode choke was entirely replaced without eliminating the fault. Somewhat puzzled, I decided that the only procedure was to continue the elimination process, and on replacing the coupling condenser the trouble was cured. This condenser was gradually breaking down, and allowing the high tension voltage from the first valve to reach the grid of the second valve in an intermittent fashion, causing the crackling in question.

Misleading Measurements.

One must always be sure, when testing a fault, that the very act of testing does not in its turn introduce misleading symptoms, or even partially cure the fault. An example of this occurred in a mains receiver with which I recently came in contact. The last valve was taking no anode current, yet the valve itself was all right. This pointed to a break in the circuit, and after some investigation suspicion was centred on the grid bias resistance. This was in series with the anode circuit, which was of the type shown in Fig. 49. Reference to this figure will show that if the grid bias resistance was broken no anode current would flow, although a voltmeter test between H.T.— and the anode of the valve would show full voltage.

Somewhat thoughtlessly I assumed that if the grid resistance was broken no voltage would be developed across it, and this point was tested with a voltmeter, only to find that it registered 50 volts—about twice the proper value admittedly, but the very presence of the voltage caused me to think very hard, and for a long time I could see no solution. In the end I took the resistance out, and checked it with an ohmmeter, finding that it really was broken as I had suspected. By connecting

a voltmeter across the resistance I had automatically completed the anode circuit, and the internal resistance of the voltmeter was acting as a grid bias resistance. Hence the reading of 50 volts.

Switch Contacts

On another receiver a sudden fade would occur without any apparent reason. Signals would be quite normal and would suddenly fade away almost to nothing. Once again the process of elimination had to be brought into play, and it was found on replacing the coils in use with others of the simple plug-in type the trouble disappeared. The original coils were of the dual range pattern, having a self-contained switch, and it was found that one of the contacts of this was making a bad high-frequency joint, although it showed perfect continuity when tested with D.C. On opening the switch and reclosing it, so that the contact was made afresh, the trouble disappeared, and on any subsequent occasion the same remedy could be applied equally successfully.

Similar trouble was experienced in a receiver in which the switch was not self-contained, but mounted entirely separately from the coil. The switch, however, was of the same pattern as in the preceding instance, being one in which two springs were forced into contact. This form of switch is liable to give trouble at high frequency, the pressure contact not always being sufficient to give a good high-frequency joint. If trouble is experienced, however, a simple opening and reclosing of the switch will usually overcome the difficulty.

Imperfect Assembly

The faults described so far have occurred in sets which were previously operating quite successfully. An unusual fault was once discovered in a hook-up on which experiments were being conducted. When the arrangement was completed, nothing whatever was received—not even the local stations. On inserting a milliammeter it was found that the first valve was not taking any current, yet an investigation of the circuit failed to reveal any obvious fault. The valve was replaced by another without making any difference to the results, and it was not until the step-by-step test with a voltmeter was carried out that there was found to be no

connection between the anode terminal of the valve holder and the valve itself. Investigation showed that the holder was defective. In the process of assembly a small insulating washer had become inserted under the terminal nut of this contact on the valve holder, so insulating the terminal from the socket.

On another occasion a somewhat similar fault occurred in a coil. A special form of soldering tag was used, having two tags, one connected to the wire on the coil and the other to the external connection from the set. The tag was held under a terminal and an additional connection had been taken to this terminal. The circuit refused to function, giving every indication of a break, yet no break in any wire could be traced. The fault was finally located to the terminal itself. Firstly, the tag was held firmly by the two wires soldered to it. Secondly, the hole in the tag was a little larger than the stem of the terminal so that it did not make contact. Thirdly, the nut on the terminal was faulty, and did not screw right home on to the tag. These three effects conspired to give a complete break between the terminal and the tag, so that the wire connected to the terminal was not in contact with the other two (see Fig. 59).

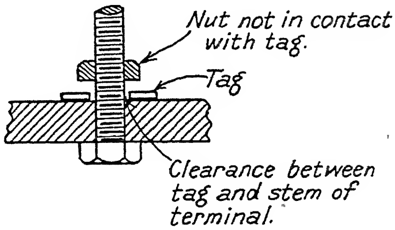

FIG. 59.—ILLUSTRATING A CURIOUS FAULT.

Pick-up Points

The attachment of a gramophone pick-up to a wireless set may sometimes give rise to trouble. If the inductance of the pick-up is high and the amplifier has a tendency towards instability, howling will occur when the pick-up is connected in circuit. The remedy is a leak across the pick-up of as high a value as will just give satisfactory stability. A more usual trouble is a howl or hum (particularly in a mains set) arising from the length of lead connecting the pick-up to the set. Most of us have, at one time or another, touched the grid of a detector valve with our fingers, and noted the resulting low-frequency howl, due to contact with an improperly earthed

body of considerable dimensions. A long lead can cause similar effects. If, however, it is necessary to use a long lead, the trouble may be generally overcome by using lead-covered wire and earthing the lead covering.

When a gramophone pick-up is attached to a set through a suitable transformer, the grid circuit is apt to become noisy since it is in close proximity to the iron core of the transformer. This trouble may be often entirely overcome by connecting the filament side of the secondary to one side of the primary (and if necessary to the core also).

Poor Quality

Another peculiar fault occurred in a battery-driven set. For months the set had been given excellent quality of reproduction, when suddenly bad distortion started for no apparent reason. The valves were found to be all right, the H.T. and grid bias battery showed full voltage, and the L.T. accumulator had just been charged.

When re-checking the L.T. voltage on the set, however, it was noticed that a reversed reading was obtained. Yet the accumulator was apparently correctly connected. A further investigation showed that the polarity of the accumulator had been reversed and on connecting it up the other way round the quality at once became normal. Needless to say the accumulator was not left in this condition but was returned poste-haste to the charging station where I had a "few bars" with the man in charge.

During a test on a powerful mains receiver some trouble was caused by a curious hum which would occur at intervals and then entirely disappear. The H.T., L.T. and grid bias potentials were all checked and found correct, whilst there was no apparent loose contact. Following the methods already outlined for testing a set, various stages were eliminated in order to discover in which portion the hum was occurring. This was done by connecting a 2 microfarad condenser from grid to filament, starting with the last valve and working back to the first stage. By a mistake the condenser was connected between the grid of the detector valve and the H.T.+. It charged with the usual spark, and the set immediately became dead silent. I thought at first that the valve

had burnt out, but to my surprise an adjustment of the dials brought in the usual stations, but without a trace of hum! Undoubtedly the charging of the condenser had cured the trouble. A careful examination of the grid circuit brought to light a bad contact in one of the leads. The current surge when charging the condenser had momentarily welded the loose contact together. Retightening this contact effected a permanent cure.

Some time ago I was asked to inspect a set built to standard design. In switching on the set, the quality of reproduction from the loud speaker was excellent for the first two minutes, after which there appeared a low hum and a "cutting up" of speech and music, entirely spoiling the reproduction. The set was examined carefully to see whether any parts were overheating and the valves were replaced one by one. Still the trouble continued. The output choke, however, had rather a smaller iron circuit than one would recommend for use with a high value of anode current, and it was decided that this might be a possible cause of trouble. On replacing it with another more suitable type the trouble completely disappeared. The most interesting feature of this fault was the gradual appearance of distortion, due to an apparent slow tiring of the iron.

On another occasion a similar effect was observed in a mains set, but this time it arose from a totally different cause. The symptoms were as before, hum and distortion gradually building up after the set had been in use for several minutes. There could be no question of saturation in this case, since constant-inductance chokes were used. The fault was discovered by systematic tests with the voltmeter. As soon as the set developed distortion it was found that the grid bias on one of the low-frequency valves had risen to an unsuitably high value, indicating that the grid bias resistance for that particular valve had momentarily increased considerably. A test across the resistance gave a reading of several megohms, yet as soon as the set was allowed to cool the resistance assumed its normal value. The trouble here was caused by the expansion of the former on which the grid bias resistance had been wound, causing a break in the wire. When the former was allowed to cool the broken ends of the wire came together again.

Jumping to Conclusions

The final fault to which reference may be made is an interesting commentary on the statements made elsewhere in this book, regarding the practice of diagnosing a fault from the noise the set makes. While in many simple cases the experienced operator can tell what the defect is from the noise which the set makes when it is switched on, sooner or later such crude methods are bound to fail, and therefore I have not stressed this aspect of the question.

The reliance I place, myself, upon such methods is limited to a few isolated cases which have already been mentioned, such as the distinctive choked sound produced by a broken grid circuit. Even such simple indications are by no means infallible as the following example will show.

The fault in question developed on a three valve amplifier, which was being tested on the bench. It gave quite good results at first, but after one or two alterations had been made it suddenly developed that curious strangled effect, usually associated with a broken grid circuit. Seeing that the apparatus was merely hooked up, I considered the possibility of a broken grid circuit quite feasible, and went over all the connections very carefully. No success attended these efforts, and the difficulty still remained.

Feeling rather peeved (because all this, of course, was wasting time, since until the fault was found I could not proceed with what I wished to), I resorted to elimination, and gradually found that the trouble still occurred even with the last valve only in circuit. I therefore spent some considerable time chasing round the grid circuit of the last valve looking for some obscure fault such as a badly assembled terminal or something of this nature.

Finally I did what should have been done at the start, applied voltmeter tests, and found that the valve was functioning quite satisfactorily. The whole trouble was that I was using a choke output circuit, and the condenser by-passing the low-frequency current onto the loud speaker had broken down. Yet the symptoms were such that I was almost certain of a broken grid circuit, and wasted considerable time trying to find a fault which was not there.

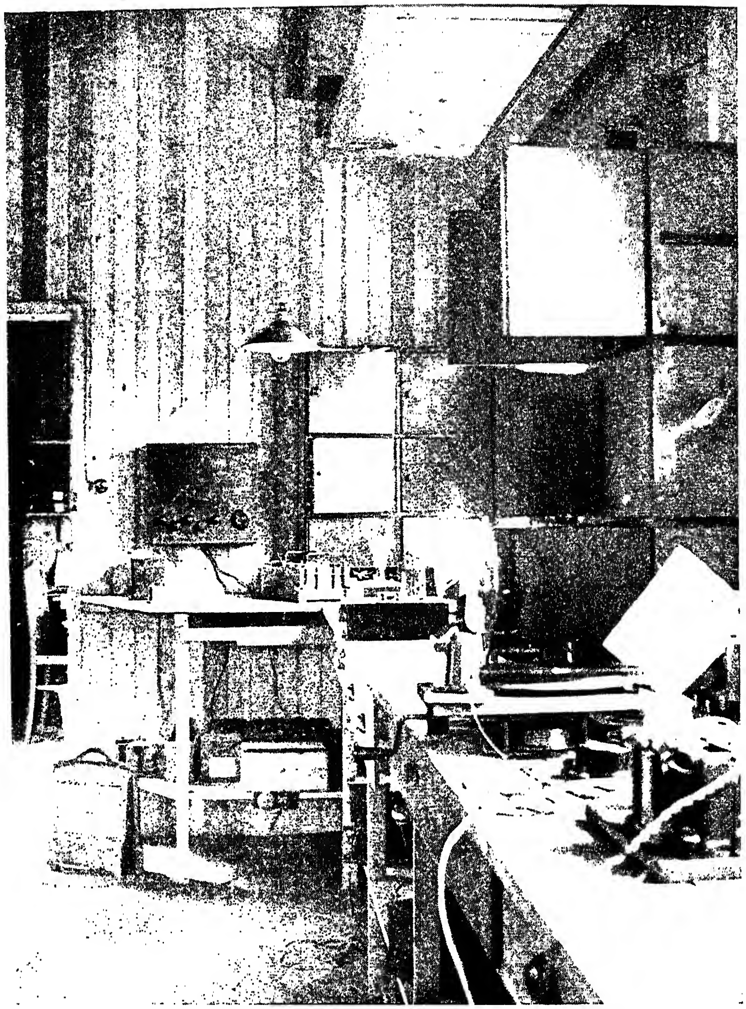

FIG. 60.—A CORNER OF THE AUTHOR'S LOW FREQUENCY LABORATORY. THE STANDARD L.F. OSCILLATOR CAN BE SEEN ON THE FAR WALL.

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SECTION II

LABORATORY TESTS

CHAPTER IX

Laboratory Testing

Laboratory or works testing, although of a more limited application than general fault testing, is of the greatest importance in the design of receivers. The usual procedure is to make an experimental model of the proposed receiver, and to find out from its behaviour whether it bears out the particular requirements or theories of the designer. In the early days the performance of a receiver of this nature was gauged by aural methods, but this is manifestly unsatisfactory for two reasons. In the first place the ear is quite unable to gauge small differences in strength. Generally speaking, it takes a critical ear to detect a change of 10 per cent. in the voltage or current. Secondly, it is very difficult for the ear to remember accurately the strength of any signal, and if one makes some alteration extending over a fair period of time, one is hardly able to gauge whether the results are better or worse. In fact the only way is to leave the original model connected up, and to make up an entirely fresh model incorporating the improvements, so that one always has a standard to work it to.

Such crude methods as this could not last long, and it is not surprising that definite scientific tests have been devised in their place. The voltages developed in various portions of the circuit were measured, and compared with theoretical expectations. By this means it was possible to determine exactly where any troubles were situated, and what remedies would best be taken to overcome them. It is a matter of relative ease to-day to make comparative tests on the amplification of the various portions of the circuit, and the science is developing to such an extent that it is now possible to

obtain overall characteristics of radio receivers in terms of the various qualities which are desirable and to rate the receiver as giving a definite performance so that one has a constant check on the progress that is being made. From the point of view of the user the application of scientific tests is of less interest. He is concerned more with whether the receiver will give him whichever stations he wants. He may be satisfied with local reception or he may wish to listen to continental transmission. The standard of quality which he demands is again a matter which varies with the individual taste. He may be satisfied with a passable reproduction which he may term "mellow" and pleasing to listen to, or he may be a stickler for the best reproduction that is possible with modern apparatus. It is even possible that he may not care what the reproduction sounds like as long as his friends across the way can hear his loud speaker! Fortunately this class of user is dying out.

Scientific data on the set is thus more of interest to designers, in order that they may make comparisons between their own models and ensure that they are making adequate progress, and also to buyers who wish to compare the relative merits of a number of sets, and who have an immediate idea from representative test figures as to the probable capabilities of the receivers in question. They can then select some of the more promising ones and to see to what extent expectations are justified by the results on an actual aerial test.

The problem has been tackled to a much greater extent in America than it has in this country, where the manufactured receiver has become a more stable product. Receivers are built in that country and marketed for a limited period, after which they become obsolete, and are replaced with next season's models. Owing to this policy and also to the large production which is possible in that country, receiver testing methods have had the opportunity of developing considerably, and the scientists have brought such tests to quite a high degree of perfection.

In this country the problem is aggravated by the difficulties of measurement, for nearly all the receivers here utilise reaction. In such circumstances it is difficult to define the high-frequency amplification of the stages up to and including the detector, for the results can be varied enormously by a

relatively small motion of the reaction condenser. It is not even satisfactory to set the reaction condenser at zero, for the whole system may be operating near the oscillation point, while a design which is thoroughly stable is perhaps penalised if a test of this nature is applied.

It is not part of this book to discuss the process of receiver testing at length. It must suffice to say that there can be little doubt as to the value of laboratory testing to the designer, and it is to be hoped that in due course scientific information may be available regarding manufactured receivers, even if this information is not necessarily imparted to the public unless asked for. It will cultivate the habit of thinking in terms of scientific facts, and this must inevitably react for the good of the radio industry.

In the following pages a brief outline will be given of the methods adopted for testing receivers, both in the research laboratory before the design is completed, and in the works laboratory during the process of production.

CHAPTER X

SIGNAL STRENGTH TESTS

THE device most commonly used for testing the performance of radio receivers is an artificial transmitter in the form of a modulated high-frequency oscillator. This oscillator must, of course, be capable of generating frequencies covering the whole waveband of the receiver, and the currents must be capable of being controlled both as regards frequency and amplitude in a convenient and ready manner. Secondly, it must be possible to modulate the radio frequency from a suitable audio-frequency source, and the extent of the modulation must be capable of being controlled and measured with satisfactory degree of accuracy.

These requirements are capable of being fulfilled with little difficulty, but the third essential—that the output of the oscillator must be under complete control—is more difficult to comply with. This requires that the whole apparatus shall be so screened from the receiver that it is not possible for any appreciable energy to be transferred from the oscillator to the receiver under test, except through the legitimate channel provided. Energy flowing in this channel is, of course, capable of measurement, and this is the basis of the whole system of testing.

In cases of scientific interest the precautions that have to be taken to ensure this complete control are extraordinarily complex. The National Physical Laboratory uses two completely screened cabins separated by a copper tube carrying the leads from one to the other. In one cabin is situated the oscillator together with its modulating arrangement, while in the other cabin the receiver and the apparatus for measuring the output are housed. Such apparatus is, of course, commercially impracticable.

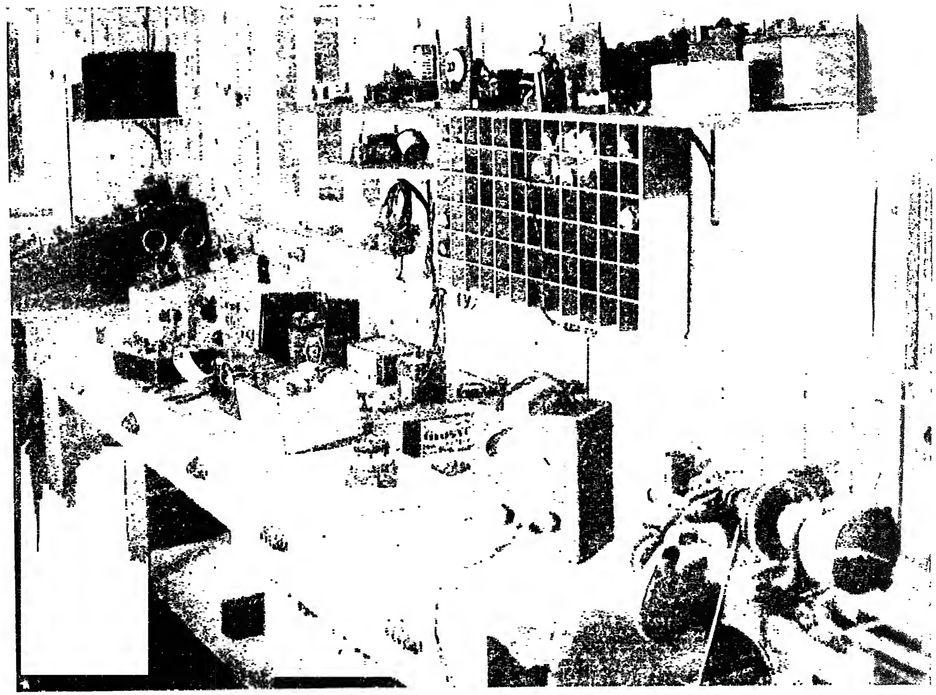

Fig. 61.—A View of the Author's High Frequency Laboratory. The Standard Wavemeter is Seen in the Background.

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In considering simpler screening, the question arises as to whether to screen the oscillator or the receiver. In some ways the latter is better practice, because the enclosing of the receiver in a screened compartment not only avoids any stray coupling with the oscillator, but also avoids direct pick-up from radio waves transmitted by broadcast stations in the vicinity which might otherwise invalidate the result. On the other hand one requires to operate the receiver, and the design of screening apparatus capable of permitting operation of the receiver, and at the same time being really screened, means virtually that one has to build an entirely screened cabin and carry out all the tests therein.

One can, of course, enclose the receiver in a small compartment with a removable front, and having adjusted the receiver satisfactorily, the front can be put in position, thereby completing the screening. One still has to have an external meter, however, and from the point of view of consistency of operation the most favourable method is that of screening the oscillator itself.

Particularly for commercial purposes where a high order of accuracy is not required, this method is quite satisfactory.

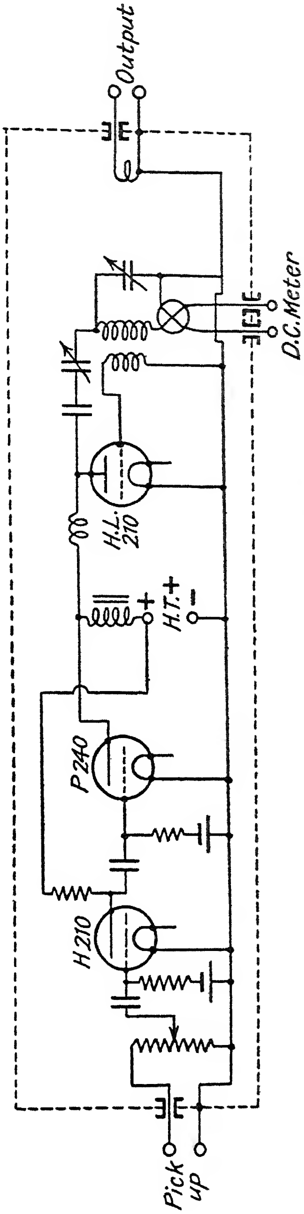

Fig. 63.—Circuit of Modulated H.F. Oscillator.

The oscillator must be very carefully screened, there being no holes or joints in the screening where such can possibly be avoided. Even the coupling leads from the output of the oscillator should be brought away in a short tube, in order to avoid any leakage of energy through the holes necessary for the leads. All batteries must be included within the apparatus, and it is usually found necessary to make the screening double, i.e. virtually to enclose the apparatus in two metal boxes, each of which is as complete as possible.

A schematic photograph of a simple set testing equipment is shown in Fig. 62. On the right is the gramophone with electrical pick-up providing L.F. currents for modulating the H.F. oscillations produced in the centre apparatus. The output is supplied to a dummy aerial coupled to a single valve set, while the voltage output from this is measured with a valve voltmeter. The circuit of this oscillator is shown in Fig. 63. The high frequency circuit will be seen to be standard in character, the modulating arrangement adopting the Heising or choke-controlled system. In accordance with customary practice the modulating valve must be capable of taking considerably more anode current than the oscillator valve, and in practice the valves specified on the circuit diagram function satisfactorily.

The measurement of the oscillating current is effected by a small vacuo-junction which is built inside the instrument, leads being taken from the D.C. side to two terminals on the case. A meter is connected to these terminals externally, this meter being clearly visible on the photograph of Fig. 62. Low-frequency modulation is supplied by means of a gramophone pick-up connected across the modulator circuit.

MODULATION

The output from the pick-up is not, in itself, sufficient to produce adequate modulation, and an extra stage of amplification has to be employed. This is clearly shown in the circuit, the whole being incorporated within the oscillator. For constant-frequency modulation, one of the constant-note records supplied by the various gramophone companies proves very satisfactory, while for ordinary testing work any suitable record may be used. For definite measurement work, of course, it is necessary to maintain a constant modulation

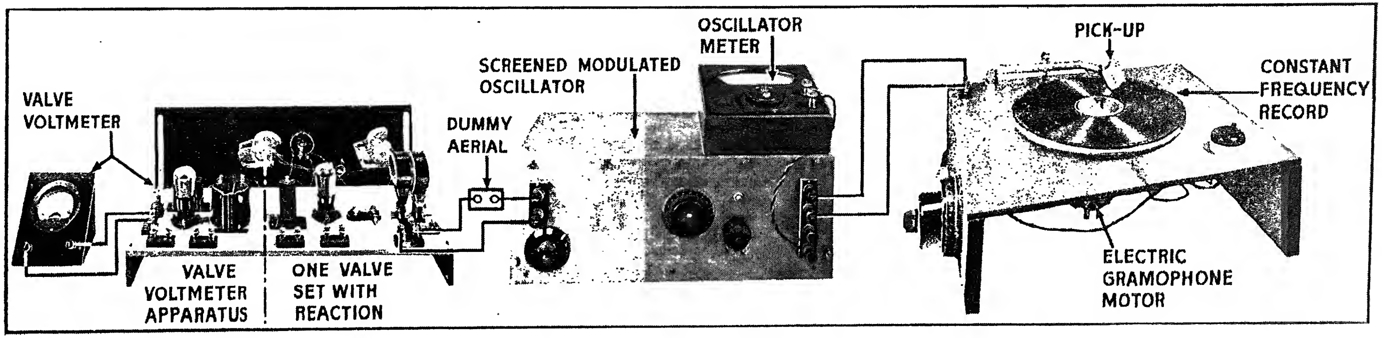

FIG. 62.—SCHEMATIC LAYOUT OF RECEIVER TESTING EQUIPMENT USED IN "AMATEUR WIRELESS" LABORATORIES.
(*Courtesy, "Amateur Wireless."*)

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and a constant frequency, and where any prolonged experiments have to be carried out, use of a gramophone is not desirable due to the continual necessity for changing the needle, etc. In such cases the output from a suitable low-frequency oscillator, as described in Chapter XI, should be connected across the input terminals in place of the gramophone pick-up. The method of operation, however, is exactly the same.

The measurement of the modulation is best carried out on this circuit by observing the alteration in the oscillating current when the circuit is modulated.

If I_1 is the current with no modulation,

I_2 is the current with modulation.

Then the percentage modulation is given by:

$$M = \sqrt{\frac{2(I_2 - I_1)}{I_1}} \times 100$$

The following table is of use:

TABLE III

INCREASE OF CURRENT WITH MODULATION

Percentage modulation.	Percentage increase in current.
15	1.1
20	2.0
30	4.5
40	8.0
50	12.5

This method, of course, has the disadvantage that if the modulation is small the increase in deflection is negligible. Actually, however, the increase becomes appreciable at about 15 per cent., and thereafter increases quite rapidly. With the customary modulation of the order of 30 per cent., the increase in deflection is quite easily readable with a comfortable degree of accuracy. Where a constant-frequency modulation is concerned, all that is necessary is to adjust the oscillating current to a suitable value with no modulation in operation. The modulating system is then brought into operation, and

the increase in current is noted. From the formula just given, the modulation can then be immediately determined, or alternatively the degree of modulation can be varied by means of the volume control until the increase in current reaches the predetermined value.

Where one is adjusting a record to duplicate an actual transmitter, it is necessary to determine the degree of modulation of some definite frequency. The modulation is largely determined by the lower frequencies, and in practice the best approximation to practical conditions is obtained by adjusting to 30 per cent. modulation at a frequency of 250 to 300 cycles per second. It does not particularly matter what frequency is chosen as long as one always makes the measurement in the same manner.

CONTROL OF OUTPUT

Having obtained satisfactory modulated current from the oscillator, the next step is the control of the output. Assuming that the apparatus is adequately screened so that, apart from a definite output coupling arrangement, no energy is allowed to escape, we have now a choice of several methods.

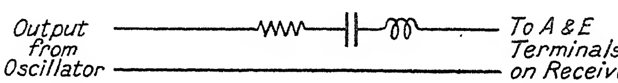

FIG. 64.—DUMMY AERIAL FOR USE IN SET TESTING.

The first method is to pass the oscillating current through a small resistance which can be calibrated. The voltage drop across this resistance can then be calculated in terms of the current and resistance. This method is quite convenient where one does not require too small an input, as otherwise the values of current and resistance become too small for satisfactory measurement.

The voltage thus generated is introduced into a dummy aerial circuit or directly into the first tuned circuit of the receiver. The latter method must, of course, be adopted where one is using a frame aerial system. The two possible methods are shown in Figs. 64 and 65 respectively.

The second method is by the use of an inductive coupling between the oscillating circuit and the output. A small

coupling coil is placed in a position such as to couple with the main oscillating circuit, and if necessary the position and/or orientation of this coupling coil must be made variable. This method has the disadvantage that the output cannot be calculated with accuracy, but it can quite easily be measured in the following manner.

Additional batteries are brought into operation in the oscillator, and an oscillating current is produced greatly in excess of that normally employed for the test. A value of 1 milliampere is usually sufficient in order to generate the very weak voltages required in ordinary practice, whereas for the purpose of this test the current may perhaps be increased to 100 milliamperes. The output voltage developed in the pick-up coil is then sufficiently large to be measurable with sufficient degree of accuracy. One can, for example, connect the output coil across a resistance of 50 or 100 ohms, values which are so high in comparison with the internal resistance of the pick-up coil that this latter factor may be neglected. The voltage across this resistance can then be measured by means of suitable apparatus such as a valve voltmeter.

FIG. 65.—ALTERNATIVE METHOD OF INTRODUCING SIGNAL INTO RECEIVER.

Another method is to make the resistance across the output coil the heater of a vacuo-junction. A sensitive junction can be obtained, in which the heater resistance is of the order of 50 to 100 ohms. By the use of this apparatus one can obtain an immediate indication of the actual current flowing in the circuit, and this multiplied by the resistance of the heater is the voltage developed, to a close degree of approximation.

The voltage developed across the pick-up coil in actual practice is then assumed to be directly proportional to the current, so that if one only uses 1 milliampere oscillating current in practice, and 100 milliamperes for the test, all the calibrations must be divided by 100. Practical experience indicates this is justifiable. The method is, of course, equally applicable to capacity coupling, and in either case the calibration must be carried out at various frequencies and a

series of calibration curves obtained, since the voltage induced is dependent on the frequency of the current.

A third method, often adopted in America, is to use an attenuator. This is an arrangement which is connected across the oscillating circuit and is so constructed that the voltage across the output is a given small fraction of the voltage across the input. The circuit diagram of such an attenuator is shown in Fig. 66. This again can be calibrated on quite large currents, and then applied to relatively small currents, such as would be encountered in the oscillator under working conditions. It is convenient to arrange the tappings in logarithmic manner so that the *ratio* of the voltages on successive tappings is constant. The decibel (dB) is a unit based on such logarithmic working and is convenient where one is dealing with large ratios such as are encountered in this class of work. For further information the reader is referred to an article by J. F. Herd in *Experimental Wireless* for January, 1929.

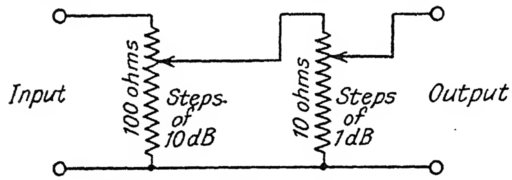

FIG. 66.—SIMPLE ATTENUATOR.

By one of these three methods, therefore, we obtain a small voltage which is known and which is applied to the input of the receiver, either by being introduced into a dummy aerial system or by being induced directly into the tuned circuit of the first valve. This will produce a signal which will be amplified by the receiver in the normal manner, and the output at various portions of the receiver can be measured. Where one is interested in a scientific measurement of overall amplification, these measurements must be made with due care and strict regard for accuracy. Where one is merely examining the performance of a receiver, perhaps in comparison with a previous model of the same instrument, one is concerned not so much with actual figures, but with comparative readings, and less stringent precautions have to be taken.

One can measure the output either in terms of the voltage applied to the grid of the detector valve (for the H.F. stages only) or carry through to the power valve where we can either

measure the volts applied to the grid or determine the power developed in suitable resistance in the anode circuit of the output stage. Alternatively, one can measure the voltages developed on the grids of the successive valves, thus obtaining a check upon the amplification of each stage.

If we are using a modulated high-frequency voltage, it is possible to do this either on the high-frequency stages or on the low-frequency stages, provided one has apparatus suitable for measuring the voltage in the various portions.

A valve voltmeter is a very convenient piece of apparatus for such a purpose. This may either be purchased already calibrated in the volts, or it may be made up and calibrated in the laboratory. A simple form of valve voltmeter is shown in Fig. 67, but for further information on this subject the reader is referred to the various articles which have appeared from time to time.

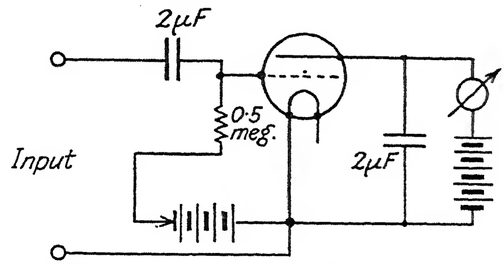

FIG. 67.—SIMPLE VALVE VOLTMETER CIRCUIT.

MEASUREMENT OF AMPLIFICATION

Where a large amplification is obtained over any one stage, it is not practicable to measure the voltages of the output and input of the same stage with the same voltmeter. The use of a different meter involves a considerable possibility of error, and in such cases the best procedure is as follows:

Let us assume that we wish to measure the amplification of a high-frequency stage. The valve voltmeter is connected across a suitable point on the output side of the stage, for example, the grid and filament of the detector valve. The voltage from the oscillator is introduced in series with the tuned grid circuit of the detector valve. The setting on the oscillator required to give a certain predetermined reading on the valve voltmeter is noted. The oscillator coupling is now removed from the detector circuit and is inserted in the tuned

circuit feeding the grid of the H.F. valve. A very much smaller voltage must now be induced in order to produce the same reading on the detector meter, owing to the amplification of the valve. The oscillator setting is adjusted until the reading of the valve voltmeter is the same as before. The ratio of the voltages induced in the two cases gives the amplification of the stage.

One must, of course, take particular precautions to avoid any coupling between the circuits which would introduce reaction effects, and invalidate the reading. In fact, throughout this measurement work the greatest precautions must be taken to ensure that the measuring apparatus does not affect the operation of the circuit in any way.

This method can be used for low-frequency measurement, and in some cases is valuable in this connection as it detects any distortion introduced by excessively sharp tuning in the high frequency stages. Low-frequency measurements pure and simple, however, are best carried out with low frequency oscillator as detailed in the next chapter.

The use of a dummy aerial has already been outlined. This consists simply of a capacity in series with a resistance and a small inductance in order to duplicate the constants of the average aerial. The voltage is induced in series with this dummy aerial, as shown in Fig. 64. Where a frame aerial is used it is not always convenient to introduce the voltage in the frame aerial circuit itself. The best method is then to induce the voltage by means of a standard inductor placed a given distance away from the frame aerial. This method is detailed in Chapter XII, where the standard regulations of the Institute of Radio Engineers are given.

MEASUREMENT OF SELECTIVITY

The use of a high-frequency oscillator is important when checking selectivity. For this purpose no modulation is necessary, the high-frequency oscillations being constant in amplitude. A valve voltmeter is connected across the grid and filament of the detector valve, or across the particular circuit arrangement under test. When the circuit is tuned to resonance with the oscillator, the deflection is, of course, a maximum, and on either side of the resonance the strength falls off.

One often requires to know to what extent this falling off occurs, for the sharper the cut-off at frequencies removed from the resonant point the more selective is the receiver. One method of achieving the results is to tune the oscillator to the receiver or circuit under test, and then gradually to mistune the oscillator on either side of the resonant point, noting the reading on the valve voltmeter for various frequencies. In this way a resonance curve can be plotted and much useful information can be obtained.

It is, of course, necessary in this case to have a valve voltmeter of which the calibration is known. All the previous methods have relied upon the use of the same reading on the valve voltmeter which is, therefore, merely a checking instrument and need not be calibrated in terms of voltage input. In the case of selectivity tests, however, one must know the calibration.

Alternatively the method suggested in the standardisation report of the Institute of Radio Engineers may be adopted (see Chapter XII), in which case the valve voltmeter need not be calibrated. Which method is adopted is a matter of personal preference.

CHAPTER XI

Low Frequency Tests

As was mentioned in the last chapter, it is preferable for low frequency work to employ somewhat different methods, unless there is some special reason against such a course. The use of a modulated high-frequency oscillator is of value in determining the distortion introduced either by the tuning circuit or by the detector circuit, and if one is endeavouring to appraise the overall performance of a receiver, this is really the only satisfactory way of obtaining information. Where one is concerned, however, with an improvement or modification in the low-frequency stages it is neither desirable nor necessary to have the high-frequency portion of the receiver in situ, and one requires, therefore, some method of testing entirely at audio frequencies.

For this purpose low-frequency oscillators are employed. These are usually of two types. The simplest type is that in which the oscillations are generated at a low frequency. A valve maintained arrangement can be constructed in accordance with the customary principles, whereby a circuit consisting of large inductance tuned with a relatively large condenser is allowed to oscillate at its natural frequency, this oscillation being maintained by utilising the amplifying properties of a valve.

Fig. 68 indicates a simple arrangement of this nature. The fundamental principle of all testing apparatus is observed in this instance, namely that the load imposed upon the apparatus shall cause as little variation as possible to the frequency or other characteristics of the supply. For this purpose a small oscillator is arranged, this being of the Hartley type, maintained in a state of feeble oscillation by a small valve having its own batteries. This arrangement may conveniently be enclosed within a screening box, so that it is as far as possible isolated from external forces.

Across this oscillating circuit is connected a high resistance, with a variable connection capable of being moved up or down the resistance. Such a device is known as a high-resistance potentiometer, and there are various types available on the market. By moving the slider of a potentiometer over the resistance one is able to obtain varying voltages across the two output terminals and these terminals are connected across the input of a suitable valve amplifier. This amplifier would be of more or less conventional construction, the particular points being that great attention is paid to maintaining a uniform frequency response, and to avoiding any suspicion of overloading throughout the stages. This would, of course, be obtained by using larger valves than are normally required, so that there can be no danger of

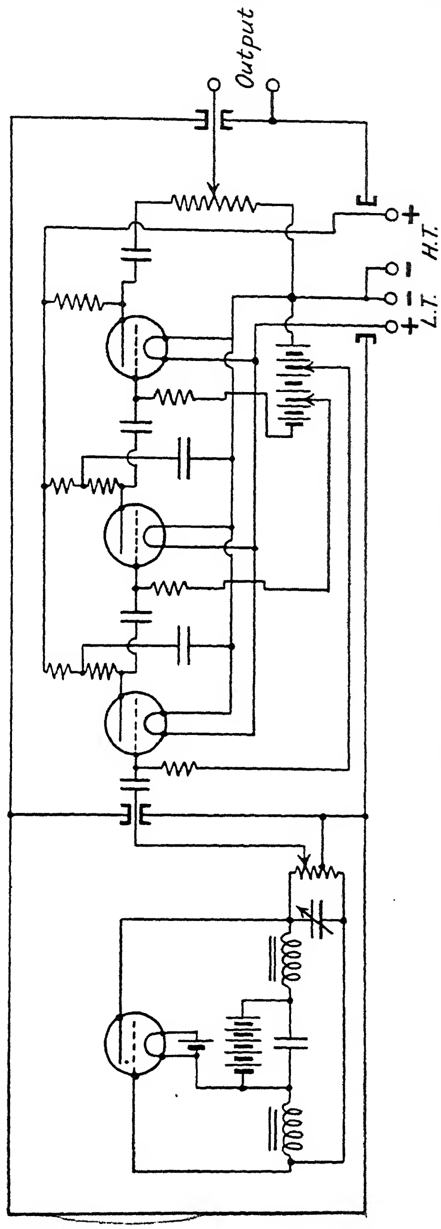

FIG. 68.—CIRCUIT OF L.F. OSCILLATOR.

operating on any portion of the characteristics other than the straight-line portion, with the object of preventing distortion. By this means the output from the oscillator can be made considerable, and yet still free from any serious harmonics. This is most important because the measuring devices usually employed are of the valve-voltmeter type and are equally as sensitive to harmonics as to the fundamental.

The particular point in the arrangement is that the load is connected with the output circuit of the valve amplifier, and is thus far removed from the oscillating circuit. Hence, whatever the form of load, or whatever alterations are made, no appreciable change takes place in the frequency of the supply or in the character of the wave form, always provided that such alterations as are made do not cause the last valve in the amplifier to distort. The method adopted for obtaining the output from the last valve varies with circumstances. Quite a convenient arrangement is to use a resistance network as shown in the figure, the actual voltage of the output stage being controlled partly by the high-resistance potentiometer on the input to the amplifier, and finally by tapping up or down this output resistance.

Fig. 69 illustrates a low-frequency oscillator of this type, made by the Cambridge Instrument Co.

Beat-Frequency Oscillator

A second form of oscillator which is much used is the beat-frequency oscillator. The disadvantages of the low-frequency oscillator pure and simple, is that great care has to be taken to avoid harmonics, while in addition it is difficult to make the circuit oscillate at the very low frequencies to a satisfactory degree. If one is particularly interested in frequencies from 50 to 100 cycles or even lower, this is a most important point. The beat-frequency oscillator overcomes these difficulties by using two high frequencies.

It is well known that if two high-frequency oscillations relatively close in frequency are combined and rectified, an audible beat note is produced between them of a frequency equal to the difference of the frequencies of the two high-frequency oscillations. This effect is commonly observed in wireless practice, when a circuit is allowed to oscillate. If it is tuned to a telephony station, the local oscillation sets up

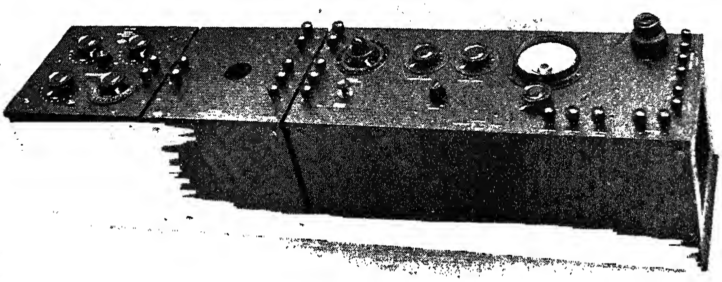

FIG. 69.—L.F. OSCILLATOR MADE BY THE CAMBRIDGE INSTRUMENT Co., LTD.

[*Facing page* 140.

beats with the carrier wave of the transmitting station, producing an audible whistle which can be varied in pitch as the tune of the circuit is altered.

This effect is deliberately utilised in the beat-frequency oscillator, two separate oscillations being set up, one of which is maintained constant in frequency, and the other is varied. Considerable precautions have to be taken in order to make the arrangement work satisfactorily. The most important of these is the complete separation of the two oscillators. If two circuits are allowed to beat together, it is found that when they come within 50 or 60 cycles of each other, they fall into step suddenly, the stronger oscillator taking control of the weaker, so that they both oscillate on exactly the same frequency. To avoid this the weak oscillator is entirely screened from the rest of the circuit, and the output therefrom is taken to a neutralised high-frequency amplifying stage. The purpose of this is to prevent any transfer of energy back from the anode of the valve through to the oscillator itself. This is a peculiar property of the neutralised circuit, and if the arrangement is symmetrically constructed, this precaution operates satisfactorily. The output from this H.F. stage is then fed to a detector valve, while at the same time the strong oscillator is made to supply current to the same detector valve. The combined frequencies are rectified, and the beat-frequency is found in the anode circuit. The high-frequency oscillations are now filtered out by being short circuited to earth through a condenser leaving us with the low-frequency current which is suitably amplified in much the same way as before.

The arrangement has the advantage that a small movement, of say, 180 degrees of a condenser dial enables one to obtain frequencies ranging from 4 to 5 cycles per second to 7,000 or 8,000, and this is very convenient in operation. The system, however, must be very carefully constructed if it is to work satisfactorily. All the high-frequency components must be completely screened from each other, and the adjustment of a neutralised H.F. stage avoiding the back coupling from the strong to the weak oscillator must be very carefully checked. Great difficulty, too, is experienced in preventing the oscillators from wandering. That is to say, that the frequency of one of the oscillators, or perhaps both, may not

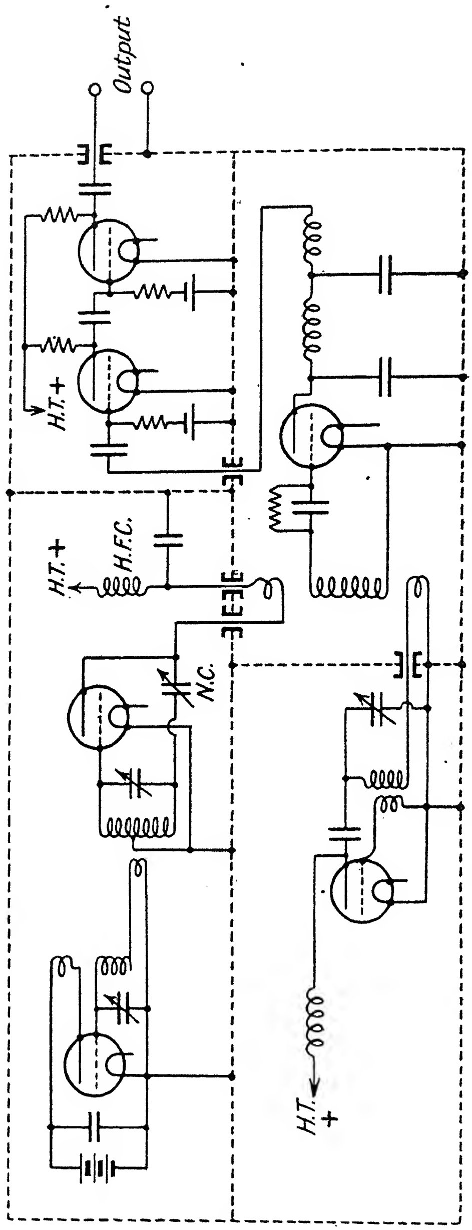

FIG. 70.—CIRCUIT OF BEAT-FREQUENCY OSCILLATOR.

remain constant but may gradually creep so that the resulting note does not stay fixed in frequency, but gradually rises and falls, depending upon circumstances.

It is impossible in the present short review to discuss the methods whereby this may be overcome, but if the system is satisfactorily constructed it is very convenient and easy in use. Fig. 70 gives a circuit showing the general arrangement.

MEASURING L.F. AMPLIFICATION

Whatever method is adopted we must have at our disposal a source of frequency of pure wave form capable of being varied in frequency from 50 to at least 5,000 cycles per second, and preferably rather more, while the strength of the oscillation

must be under complete control without any alteration to the quality. Once we have this system available we can proceed with the testing of the amplifier.

The low-frequency amplification of a receiver or circuit may be tested in much the same manner as is adopted in high-frequency tests. The oscillator is connected to the amplifier and the voltage across the output is measured by means of a suitable device such as a valve voltmeter. This device must, of course, be so connected that it causes little alteration to the circuit under test. The voltmeter is left connected across the output and the voltage is introduced from the oscillator at two points in the circuit, one just before and one just after the stage being measured. The oscillator setting is adjusted to give the same reading on the voltmeter in each case. The ratio of the two oscillator settings then gives the amplification of the stage in question.

There are varying methods which can be utilised for altering the output from the oscillator. The use of the potentiometer across the oscillating circuit itself may be used to control the current, but it cannot be used with any accuracy for determining the actual output. Therefore, some suitable measuring system must be adopted, and here a number of possible variants may be employed.

One is illustrated in Fig. 71, where the output from the oscillator is fed to a resistance in series with which is a meter for reading the current. This may either be a thermal meter, or a rectifier meter as described in Chapter I. The current through this resistance can be varied by operating the potentiometer on the oscillating circuit, and since the voltage output from the oscillator is obtained by multiplying the current by the resistance, this gives an indication of the voltage developed. This method is only satisfactory for comparatively small amplifications, because it is not satisfactory to vary the current over a ratio of more than about 10 to 1.

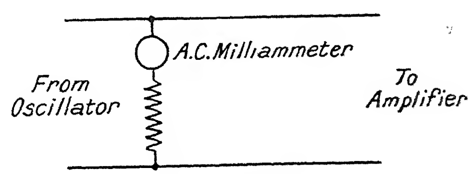

FIG. 71.—OUTPUT MEASURING CIRCUIT.

A better method is to use a potentiometer system across

the output. Low resistances, of the order of 2,000 ohms only, must be used here, as otherwise the self-capacity of the resistances may introduce errors at the higher frequencies. Provided the total resistance is of the order of 2,000 ohms, however, a potentiometer, as shown in Fig. 72, may be used

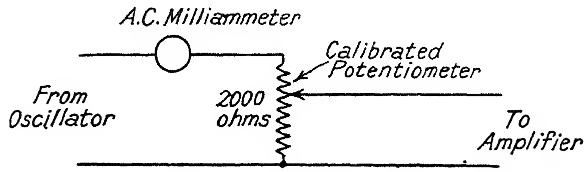

FIG. 72.—AN ALTERNATIVE SYSTEM OF MEASURING OUTPUT.

quite satisfactorily, and here ratios of several hundreds may be measured quite satisfactorily.

Where one is concerned with the response curve of an amplifier as a whole, a slightly different method is adopted. Here arrangements are made to apply a constant input to the amplifier, and the circuit shown in Fig. 71 may be adopted quite satisfactorily. Whatever the frequency of the oscillator, the current is then always adjusted to be the same so that the voltage applied to the amplifier is constant. The voltmeter is then connected across the output stage, and the reading on this voltmeter is noted at the various frequencies. If the amplifier gives a uniform magnification over the whole frequency scale, the reading on this output meter will, of course, remain constant, but in practice it does not do so, there being variations at different parts of the frequency scale, which are shown by the variation in reading of the output meter.

The connection of the output meter depends upon the circumstances. If one is not interested in the effect of the loud speaker on the characteristics, as is very often the case, it is sufficient to connect the meter across the grid circuit of the output valve. The output valve itself should be left in circuit with the loud speaker connected up in order to duplicate practical conditions.

If, on the other hand, one desires to include the magnification obtained from the output stage, then the voltmeter should be connected across the loud speaker or across a

resistance in the output stage designed to give the optimum result, according to which is preferable. With any output valve the loud speaker impedance should bear a definite relationship to the internal resistance of the valve for maximum undistorted output, and in many instances this impedance is evaluated, and an equivalent resistance is connected in the anode circuit of the valve across which the voltmeter is connected.

CHAPTER XII

American Test Data

The Year Book of the Institute of Radio Engineers for 1929 gives some useful information regarding tests of radio receivers. The data is in the form of a standardisation report drawn up by the leading engineers in the country. Some extracts from this report are given herewith.

The general scheme is of the form already outlined in the preceding chapters. The tests suggested are:

1. *Sensitivity*. Voltage is applied to the receiver from a modulated high frequency oscillator, and is adjusted in intensity until a given output is developed across a resistance inserted in the last stage of the receiver. This resistance takes the place of the loud speaker, and its value is chosen as defined under *Normal Test Output*. It is stipulated that the radio frequency shall be modulated 30 per cent. at 400 cycles per second. This test is carried out at a number of standard carrier frequencies.

2. *Selectivity*. This is the degree to which the receiver is capable of differentiating between signals of different frequency. The receiver is tuned to the oscillator at one of the standard test frequencies and the input adjusted until the *Normal Test Output* is obtained. The radio-frequency oscillator is then mistuned by an amount not exceeding 10 kilocycles, and its strength adjusted until the Normal Test Output is again obtained. The readings are continued in steps not exceeding 10 kilocycles on each side of the tuning point until the radio frequency input is at least 100 times the value at resonance, or until a range of 100 kilocycles on either side of the resonant point has been covered. The arrangement, of course, gives an inversion of the customary resonance curve.

3. *Fidelity*. The receiver is tuned to one of the standard test frequencies, and the input is adjusted to give *Normal*

Test Output on the receiver. The modulation is then varied in suitable steps from 40 to 10,000 cycles per second, the percentage of modulation being maintained constant at 30 per cent. The output obtained in each case is noted and the results are plotted as a percentage of the output obtained with the standard 400 cycle modulation.

4. *Normal Test Output* is defined, for a broadcast receiver, as an audio frequency power of ·05 watts, in a non-inductive resistance adjusted to give maximum power output per volt input. It should be noted that the condition laid down is not maximum undistorted power output, but since the power output of 50 milliwatts represent a relatively small volume, there is little danger of overloading the last valve. The minimum power customarily employed in an ordinary living-room is 100 milliwatts.

Details are given in the following pages as to the methods to be adopted in making these measurements. Where the receiver does not employ a loop or frame aerial, an artificial aerial is used, the requirements for which are a capacity of 200 $\mu\mu$F, a self-inductance of 20 μH, and a resistance of 25 ohms.[1] The effective height of the aerial system is taken as 4 meters, so that the field strength is obtained by dividing the actual radio-frequency voltage impressed upon the receiver by 4.

It is emphasised, in the Report, that the apparatus employed in testing radio receivers should be as simple as is consistent with accurate performance of the necessary functions. As far as possible, the same apparatus should be used in the different tests. The values of the electrical quantities and the calibrations should not change with time; or if some change is unavoidable, means for checking should be provided.

The required apparatus, for tests of sensitivity, selectivity and fidelity, is indicated schematically in Fig. 73. Both frequency sources should be calibrated so that separate measurement of frequency is not needed. The requirements of the separate elements are stated in the following paragraphs.

[1] This resistance is at H.F. and must therefore consist of a short length of very thin wire, so that the H.F. resistance is substantially the same as the D.C. resistance. 43 S.W.G. Eureka is suitable for frequencies up to 1,500 kilocycles.

1. *Audio-Frequency Source.* For sensitivity and selectivity tests this may be a mechanical oscillator of fixed frequency (400 cycles per second), but a vacuum tube oscillator having a frequency range at least from 40 to 10,000 cycles per second is preferred, and for the Fidelity test is necessary. The total harmonic content in the output of this oscillator should not exceed 5 per cent. The audio-frequency oscillator is arranged to modulate the radio-frequency oscillator by a

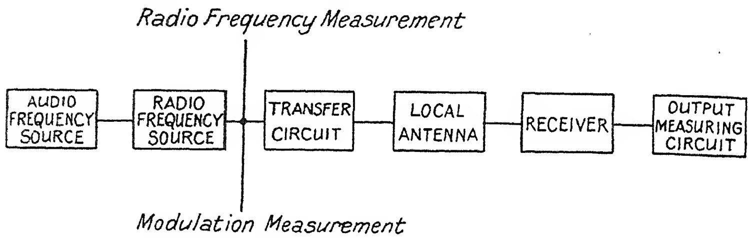

FIG. 73.—ILLUSTRATING METHOD OF TESTING RECEIVERS.

known amount, and preferably should furnish the same degree of modulation without readjustment at all carrier frequencies and all modulation frequencies. Means should be provided for adjusting the degree of modulation for at least the normal value of 30 per cent.

2. *Radio-Frequency Source.* This consists of a vacuum tube oscillator supplied preferably from batteries, either fully shielded in itself or so shielded from the radio receiver under test that there is no direct radiation to the receiver. If the power supply is external to the shielding system which encloses the oscillator, all unearthed leads to the oscillator should pass through shielded low-pass filters. The frequency should be adjustable by an external control to any desired value between 500 and 1,500 kilocycles per second, and the frequency should not be affected by changes in output power. Means should be provided for varying the frequency in small steps immediately on each side of any specified frequency. A second external control should be provided for varying the modulated radio-frequency output supplied to the transfer circuit, and an instrument should be provided which indicates the effective value of this output. The oscillator in conjunction with the transfer system used should be capable of supplying in series

with the receiving antenna system at least 200,000 microvolts at all carrier frequencies.

3. *Transfer Circuit.* The radio receiver under test is provided with a local antenna circuit consisting of either a loop antenna (which may be self-contained) or an artificial antenna. In determining the significant characteristics, as outlined in the preceding sections, modulated radio-frequency voltages of known value are impressed in the local antenna circuit through the transfer circuit which should assume one of two forms as follows :

(*a*) A coupling coil fed from the radio source and mounted in inductive relation with the loop antenna or with the 20 microhenry inductance coil of the artificial antenna. In the latter case, the coupling coil is used as the primary of a calibrated mutual inductor, the secondary of which is the 20 microhenry coil.

(*b*) A calibrated attenuator of the resistance type terminating in a low impedance of known value (usually a resistance of about 1 ohm) which may be inserted in series with the artificial or loop antenna. This attenuator should be so constructed that all attenuation ratios are substantially independent of frequency within the broadcast band. It is preferably made variable in steps with additional provision for continuous variation between the steps. As an alternative to continuous variation within the attenuation network, provision may be made for continuously varying the measured current or voltage supplied from the source to the attenuator over a sufficient range to cover all values of receiver input voltage which lie between the steps of the attenuator. Design details of attenuators fulfilling these requirements are available in the literature. The combined range of ratios on the attenuator and variable currents from the source should be such as to allow a range of voltage across the terminal unit which feeds the receiving set of 1 microvolt to 200,000 microvolts.

4. *Output Measuring Circuit.* The components of the output measuring circuit should be as follows:

A non-inductive load resistor adjustable by calibrated taps and covering a range of 1 to 10,000 ohms and capable of dissipating 0·1 watt at any setting.

An output filter to be used with radio receivers normally

having D.C. in their outputs. A recommended form consists of an inductance of not less than 100 henries (with 10 milliamperes D.C. in the winding), and a capacitance of not less than 8 microfarads arranged as shown in Fig. 74.

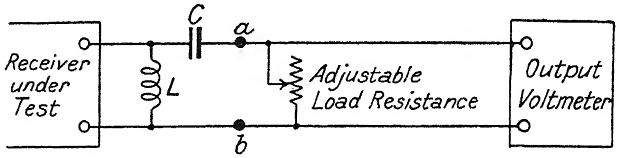

FIG. 74.—CHOKE-OUTPUT ARRANGEMENT FOR AVOIDING DIRECT ANODE CURRENT IN OUTPUT CIRCUIT.

A vacuum-tube voltmeter or an equivalent device which will measure accurately the R.M.S. values of output voltage. At normal test output the voltage is of the order of from 10 to 20 volts for ordinary output vacuum tubes. For the sensitivity and selectivity tests the output meter need be calibrated only at these values. For the fidelity test, continuous calibration is required.

TEST PROCEDURES

1. **Preliminary.** The present day radio receivers vary so greatly in their manner of operation that it is difficult to set down a single test procedure for each fundamental characteristic, and have the procedure include all the allowances that should be made for the peculiarities of different sets. It is simpler to describe in general the test setups and adjustments

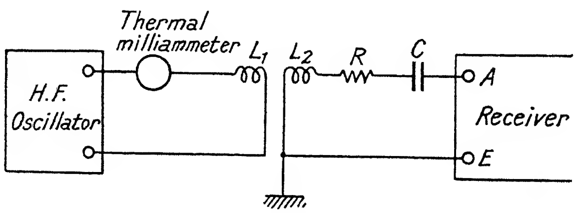

FIG. 75.—INDUCTIVELY-COUPLED PICK-UP SYSTEM.

of input and output; the operating conditions; and the radio receiver adjustments as applied to any type of receiver,

and then standard procedures for measuring sensitivity, selectivity and fidelity, can be outlined.

2. Input Measurements.

(*a*) *Radio Receiver without a self-contained antenna.*

Standard input circuits are shown in Figs. 75 and 76. Either circuit may be used depending on whether an impedance device or a mutual inductance is used to attenuate and introduce the radio-frequency voltage in the artificial antenna circuit.

The mutual inductor is used as shown in Fig. 75. The input to the receiving set is controlled by adjustment of either the coupling between coils L1 and L2 or the current through L_1. The assumed value of radio field intensity impressed on the radio receiver is determined from the formula.

$$\mathcal{E} = \frac{2\pi f M I}{h} \text{ microvolts per meter, where}$$

f is the carrier frequency in kilocycles per second.

M is the mutual inductance between L_1 and L_2 in millihenries ;

I is the current through L_1 in microamperes ;

h is the antenna height in meters (4 meters for the standard antenna).

The circuit for use with an impedance coupling device is shown in Fig. 76. The voltage impressed in series with the

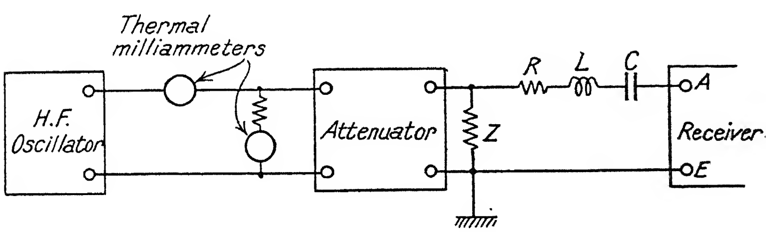

FIG. 76.—ILLUSTRATING USE OF ATTENUATOR.

artificial antenna is brought to the desired value by selecting the proper degree of attenuation and accurately adjusting either the current or the voltage input to the attenuator. If the attenuator is calibrated in terms of current, the radio

field intensity impressed in the artificial antenna may be expressed as :

$$\mathcal{E}=\frac{KZI}{h} \text{ microvolts per meter,}$$

where

K is the attenuation factor

Z is the impedance of the coupling device ;

I is the measured value of current fed to the attenuator in microamperes ; and

h is the assumed antenna height in meters (4 meters for the standard antenna).

If the attenuator is calibrated in terms of voltage and includes the impedance *Z*, then :

$$\mathcal{E}=\frac{KV}{h} \text{ microvolts per meter}$$

where

K is the attenuation factor ;

V is the measured voltage input in microvolts ;

h is the assumed antenna height in meters (4 meters for the standard antenna).

(*b*) *Radio receiver with a loop antenna.*

An arrangement of apparatus as shown in Fig. 77 is recommended.

A known radio field intensity is impressed on the loop antenna by adjusting the distance *X* and the current through the coil *L*. The coil and loop antenna centres are kept on a common axis, and the distance *X* kept large as compared with the dimensions of the loop antenna.

The radio field intensity is :

$$\mathcal{E}=\frac{18{,}850\, NA^2I}{(A^2+X^2)^{3/2}} \cos B \text{ microvolts per meter,}$$

where

N is the number of turns in the coupling coil *L* ;

A is the radius of the coupling coil, in centimetres ;

I is the ammeter reading in microamperes ;

X is the distance in centimeters between the centre of the coupling coil and the centre of the loop antenna ; and

B is the angle, if any, between the axis of the loop antenna and the line between coil centres.

The radio-frequency voltage may be introduced in the loop antenna by inserting the terminal impedance of a resistance type attenuator in series with the loop at a point of earth potential in a manner similar to that shown for an artificial antenna in Fig. 76. In this case, the equivalent radio field intensity is given by the expression:

$$\mathcal{E} = \frac{E}{Q} \text{ microvolts per meter,}$$

where

E equals the voltage across Z in microvolts, and

Q equals reception factor in metres of the loop antenna employed.

The factor Q may be calculated approximately for a rectangular loop from the relation:

$$Q = 2\,N\,H\,sin\,\frac{\pi f s}{300{,}000}, \text{ where}$$

N = the number of turns;
H = the height of the loop in metres;
s = the length of the loop in metres, and
f = the frequency in kilocycles.

It is not appropriate to specify a standard loop reception factor because the loop antenna is frequently a characteristic element of the radio receiver under test.

The method first described adapts itself best to the testing of loop receivers because it leaves the loop circuit in its normal

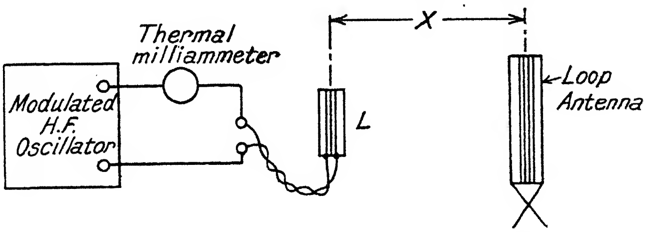

FIG. 77.—ARRANGEMENT WITH LOOP ANTENNA.

form. If the second method is applied to the testing of a loop radio receiver, the output terminal unit of the attenuator should be of low impedance and have a resistance which is low compared with that of the loop.

3. Output Measurements.

(*a*) *Radio receiver with D.C. in its output.*

If the radio receiver is not equipped to filter direct current from its output, the circuit which should be used in making output measurements as is shown in Fig. 74.

The value for R is dependent on the operating conditions of the output valves used in the radio receiver and is arbitrarily taken as the plate resistance value given by the valve manufacturer for that valve under the given conditions.

In the case of a radio receiver having an output transformer, R is taken as the reflected value of the valve resistance, or

$$R=\frac{R_p}{A^2}$$

where

A =the transformer ratio of primary to secondary turns; and
R_p=the value of valve plate resistance.

The voltage across R for normal test output is:

$$V=\sqrt{0{\cdot}05\ R}$$

(*b*) *Radio receiver with no D.C. in output.*

If the radio receiver has a device eliminating direct current from its output (referring to the circuit of Fig. 74), L and C are removed and the points a and b connected directly to the output terminals of the receiver.

(*c*) *Radio receiver with extraneous voltages in the output.*

The voltages due to *A.C.* hum, valve noises, etc., that may exist across the output of some radio receivers must be considered where the output voltage to be measured is small. For example, if these voltages are comparable with the normal test output voltage, let the voltage across the resistor R for normal test output be:

$$V=\sqrt{V_1^2+V_2^2}$$

where

V_1 is the R.M.S. voltage due to extraneous effects, and
V_2 is the value for normal test output voltage which gives 0·05 watt power in R.

In any case, if the extraneous voltage is appreciable, the measured voltage across R (see Fig. 74) should be considered as the vector sum of the extraneous voltage and that due to the desired signal.

APPENDIX

COMPONENT TESTING

In following out the methods outlined in the chapters of this book, one may be faced with the necessity for making some form of test on a particular component in order to determine whether it is working satisfactorily or not. The discussion of any elaborate methods of testing is clearly beyond the scope of this work, but some of the simpler forms of test which can be carried out with a relatively limited amount of apparatus, may be given with advantage. The object of this Appendix is to indicate the methods which may be adopted in practice.

CONDENSER TESTING

Continuity

One of the first tests which has to be made on a variable condenser is that of ensuring that the plates are not touching. This may very simply be done by means of a pair of telephones and a small battery of $1\frac{1}{2}$ to $4\frac{1}{2}$ volts. This is arranged as shown in Fig. 78, and on connecting up the circuit a loud click will be heard in the telephones if there is a short circuit. If the condenser is properly insulated only a faint click will be heard.

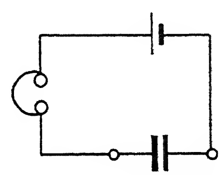

Fig. 78.—Continuity Test with 'Phones and Battery.

If desired a milliammeter may be used in place of the telephones, but a safety resistance should be included of such a value that if the condenser is short circuited, current will not be excessive through the milliammeter. To determine this, divide the voltage of the battery by the maximum reading on the milliammeter in milliamps. This will give the resistance required in thousands of ohms. For example, a $4\frac{1}{2}$ volt battery used with a milliammeter reading 10 milliamps would require 450 ohms safety resistance. A value two or three times as

large as this may be used, provided that if the condenser is short circuited a satisfactory current reading will be obtained, whereas if the condenser is in order, no current will flow.

Capacity

It is often required to know the capacity of a condenser, and here the simplest test is to use the buzzer wavemeter. Connect up the circuit as shown in Fig. 79. Various methods must now be adopted according to the circumstances. If one has a condenser of known capacity, the first step is to connect this known condenser across the coil L and to tune in the wavemeter until the maximum signals are obtained in the telephones. Note the wavelength at which this occurs. Now replace the known condenser with the unknown capacity and again repeat the performance.

The unknown capacity is obtained from the expression :

$$C=\left(\frac{\lambda}{\lambda_1}\right)^2 C_1$$

where

C_1 =known capacity ;
λ_1 =wavelength with known capacity ;
λ =wavelength with unknown capacity.

The method can only be used satisfactorily where the unknown condenser is reasonably large, say ·0001 μF or more,

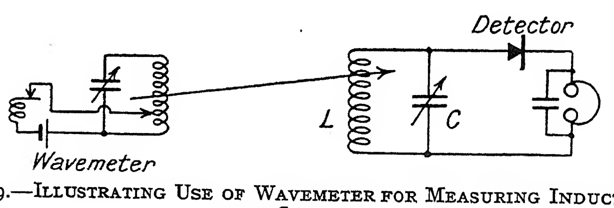

FIG. 79.—ILLUSTRATING USE OF WAVEMETER FOR MEASURING INDUCTANCE AND CAPACITY.

and it should, of course, preferably be somewhat similar in value to the known capacity employed.

If one has no condenser of which the value is known, or such that the rated value may be assumed to be correct, it is necessary to obtain a coil having an inductance which is known within reasonable limits. Such coils, for example, as the Dimic range, marked by Messrs. McMichael, Ltd., are

rated in inductance values, and this rating is sufficiently accurate for practical purposes. A Dimic No. 1 having an inductance of 200 microhenries is a very convenient coil. Use this for the coil L in the circuit, and connect the unknown capacity across it. Find the wavelength to which the combination is tuned, when the capacity will be given approximately by the expression:

$$C = \frac{\lambda^2}{3 \cdot 55 L} \times 10^{-6} \text{ microfarads}$$

where

L = inductance in microhenries.
λ = wavelength in metres.

This method again is liable to inaccuracy due to coil capacities, etc., if the capacity to be measured is less than about ·0001 μF.

Neither method is suitable for capacities exceeding about ·001 μF, owing to the fact that tuning becomes very flat with a large capacity. Incidentally, if one has any idea of the value of the capacity, it is as well to work out the approximate wavelength to which the combination will tune from the formula:

$$\lambda = 1885 \sqrt{LC}$$

where

λ is the wavelength in metres.
L is the inductance in microhenries.
C is the capacity in microfarads.

This will save time in finding the correct wavemeter setting. For measurement of larger capacities the use of a bridge method is desirable. This involves the use of a calibrated standard variable condenser, and is beyond the scope of this work, but some brief details are given later.

All the foregoing remarks apply to fixed condensers as well as variable condensers. A fault which is often found in fixed condensers, particularly of cheap manufacture, is that there is a complete break inside the condenser. The component, therefore, gives every indication of being a correct condenser, but actually has no capacity. Such a defect is, of course, shown up at once by the use of check such as that described.

Some indication of the value of capacity with a large condenser of ·001 μF up to ·01 μF can be obtained by the use of the series method. The circuit already shown is connected up, using a known value of capacity of about ·0005 to ·001 microfarads. The circuit is then broken and the unknown condenser is inserted in series with the main condenser as shown in Fig. 80. The effective capacity of the combination is then again determined exactly as previously explained by observing the alteration in the wavelength to which the combination tunes. This new capacity will be less than the original capacity, being made up of the unknown condenser and the known condenser in series. From this, the capacity of the unknown condenser may be evaluated from the expression:

$$C_x = \frac{C\,C_s}{C - C_s}$$

where

C_x is the unknown capacity.
C is the known capacity.
C_s is the capacity of the two in series.

The disadvantage of this method is that as the unknown capacity increases in value, relatively large changes in its capacity cause small changes in the series capacity, and, therefore, the accuracy is limited, but one can at any rate determine with some degree of approximation what the value of capacity is.

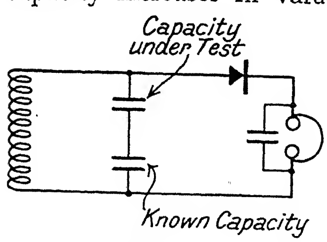

Fig. 80.—Method for Use with Large Capacities.

Paper Condensers

When one comes to very large fixed condensers such as are usually used for battery by-passing, etc., tests for capacity are beyond the means of the average user. One can, however, check such condensers for their insulation, and this is a most important property. The only reliable test for this is to make some form of charge-holding test. If a battery of, say, 100 volts is connected across the condenser, it will become charged. If the battery is now removed the condenser will remain charged, and if it is a good condenser, and the insulation

is up to standard, this charge should be maintained for at least five minutes, and much longer in the case of a really high class condenser. If, on the other hand, there is a leakage on the condenser, either internally or due to surface leakage between the terminals, the charge will leak away very rapidly.

Our test, therefore, consists in connecting a battery across the condenser, removing the battery and leaving the condenser for five minutes. At the end of this time the condenser must be tested to see if it is still charged. This may conveniently be done by connecting a screwdriver across the terminals. If the charge is still in the condenser, it will discharge with a slight spark.

If one possesses a high-resistance voltmeter, such as is used for eliminator work, one can make a more definite test than this. Connect the battery across the condenser in the usual way, and then, having removed the battery, connect the high-resistance voltmeter across the condenser. This must be done quickly, and with one eye on the voltmeter reading. The needle will flick over to a certain value, and then will gradually discharge, falling away more or less rapidly, depending upon the capacity of the condenser and the resistance of the voltmeter. The point is that the maximum reading to which the needle mounts before it commences to fall back again should be noted.

The condenser should now be charged again by means of a battery in the same direction as before, and left to stand for five minutes. At the end of this period the voltmeter should again be connected across the condenser and the maximum reading on the voltmeter noted. If there has been no loss of charge due to leakage in the intervening five minutes, the voltmeter reading will be much the same as before, within the limits of observational error. A marked discrepancy indicates that the condenser has a leakage of some sort across it, while if there is no reading at all, the condenser has lost all its charge and there is a serious leakage.

COIL TESTS

Simple matters such as continuity are best determined by a battery and milliammeter as for a condenser, or better still with an ohmmeter. One occasionally requires to know the inductance of a particular winding. This again may be

determined by the use of a buzzer wavemeter. Connect across the coil a capacity of anything from ·0003 μF to ·0005 μF the circuit being arranged in the same way as in Fig. 79. Tune in to this circuit with a buzzer wavemeter. The wavelength reading, of course, will be determined by whether the coil is a long-wave or short-wave coil, and the wavemeter range can be selected accordingly. Having found the wavelength to which the combination tunes, the inductance may be obtained from the expression:

$$L = \frac{\lambda^2}{3 \cdot 55 C} \times 10^{-6} \text{ microhenries}$$

where

C = capacity in microfarads.
λ = wavelength in metres.

If one does not know the value of the condenser which is being used to tune the circuit, a standard inductance may be used, the circuit being tuned with the same condenser both with the unknown inductance then with the standard inductance. Knowing the wavelength in the two cases, the value of the unknown inductance can be determined from the expression:

$$L = \left(\frac{\lambda}{\lambda_1}\right)^2 L_1$$

where

L_1 = known inductance.
λ_1 = wavelength with known inductance.
λ = wavelength with unknown inductance.

L.F. TRANSFORMERS

The only test which one can make in ordinary practice on low-frequency transformers is that for broken windings, or a short circuit to the core. The method for testing for continuity with a battery and a pair of telephones is *not* reliable in this case, because of the large self-capacity of the winding. This causes a loud click to be heard in the telephones, due to the charging of the self-capacity, even when the winding is defective.

The only test, therefore, is the milliammeter test. The general resistance of a transformer primary is in the neighbourhood of 1,000 to 2,000 ohms, and anything from 5 to 10 times

this value for the secondary winding, due to the fact that more turns are employed and also finer wire is used. The current which will flow through such a resistance can easily be determined, knowing the voltage which is applied across the transformer, and this current can be so arranged that it is comfortably readable on the milliammeter in question.

Let us suppose, for example, that our milliammeter has a full scale reading of 30 milliamps. Any reading from 5 milliamps up to 30 milliamps will, therefore, be suitable. Let us assume that our transformer resistance is about 1,000 ohms. Then if we put a 9 volt battery across the primary we shall obtain 9 milliamps. If we are considering the secondary, we shall have to use something in the neighbourhood of 50 volts in order to get a corresponding deflection owing to the distinctly higher resistance of the winding. The actual relationship between current, voltage and resistance is discussed at length in the section on resistance measurement.

One may find that one of the two windings is broken or that it has a much lower resistance than one would anticipate, which indicates short circuited turns. In some cases one finds that the windings are reversed. In such a case, the high resistance winding will be found across the primary terminals and *vice versa*, and the transformer would act as a step-down arrangement. This, of course, is quite in order if we are dealing with an output transformer intended to give us a step-down, but in this case the high-resistance (primary) winding will have a resistance of 1,000-2,000 ohms, while the secondary will be anything from a few ohms to a few hundred ohms, depending on the step-down ratio.

One further test which one may have to make is for a short circuit between one of the windings and the core of the transformer. This may be done by connecting the milliammeter through a safety resistance of some sort, such as 1,000 ohms, between one terminal of one of the windings and the core of the instrument. If the insulation is satisfactory, no current will flow, but if there is a complete or partial short circuit a certain amount of current will be indicated. This should be repeated for both primary and secondary windings, while, if necessary, a similar test can be made between the primary and secondary windings to make sure that there is no connection between the two windings. This, of course, is

undesirable, as it would lead to the introduction of a positive voltage on the grid of the succeeding valve, thereby causing it to refuse to function correctly.

In some cases where an auto-coupled arrangement is used, there is, of course, a direct connection between the two windings, but these cases are special.

Where one is dealing with insulations of this nature between windings and cores or winding and winding, it is advisable to use an increased voltage and to apply the test in the same way as one would use for testing an anode resistance or grid leak. This is detailed in the section on Resistances.

RESISTANCE TESTING

This question of resistance testing is perhaps one of the most important, for according to the resistance of a particular path between two points, so one learns more about it than is possible by a direct continuity test. A simple example, is the case of a dual range coil. Between the appropriate terminals one should have either a large or a small inductance, depending upon the wavelength range to be received. The change-over is controlled by a switch. Is this switch correctly marked or has it been inadvertently wired up incorrectly? This may at once be checked by measuring the resistance across the terminals. In the long wave position the resistance will, of course, be distinctly greater than on the short waves, owing to the larger number of turns of wire. Direct continuity tests would fail to discriminate between the two.

The basis of resistance testing is the well-known "Ohm's Law." This states that the voltage developed in the circuit is equal to the product of the current and the resistance. We may state the fact in a variety of ways, suited for various purposes, as shown below.

$$E = IR \text{———} (1)$$

$$R = \frac{E}{I} \text{———} (2)$$

$$I = \frac{E}{R} \text{———} (3)$$

where I = current in amperes.
E = voltage in volts.
R = resistance in ohms.

If we are not in possession of an ohmmeter (an instrument calibrated to read directly in ohms, as described in Chapter I), we must use a battery of known voltage and measure the resistance by determining the current flowing in the circuit. It is advisable to use an accumulator for this purpose because the voltage on an accumulator can usually be taken as approximately 2 volts per cell, and does not fall rapidly with load, whereas a dry battery may fluctuate quite badly according to the amount of use, and the load taken from it. Strictly speaking, one should connect the circuit up as shown in Fig. 81. Here we have a voltmeter which reads the voltage across the circuit, with a milliammeter (or ammeter) for reading the current flowing. Knowing these two properties the resistance may easily be determined. It should be noted that the milliammeter or ammeter in use must be of a high quality, as otherwise it will contain itself a certain internal resistance which will invalidate the result unless one makes special calculations to allow for this defect. Provided one uses a good moving-coil instrument, however, no difficulty will arise from this source.

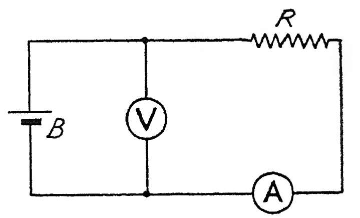

FIG. 81.—CIRCUIT FOR MEASURING RESISTANCE.

In practice one can usually dispense with the voltmeter across the battery provided one is using an accumulator, or one can, particularly where a combination instrument is employed, measure the voltage of the battery before the test is commenced. The instrument may then be disconnected, converted to a milliammeter, and inserted in series with the circuit in order to measure the current. One should always obtain some idea as to the probable order of resistance, and make a rough calculation to determine what the current will be in order to avoid overloading the milliammeter. For example, if one wished to measure a resistance of 10 ohms, this connected across a 2 volt battery would draw a current of 200 milliamps. If one's meter only reads up to 30 milliamps, a serious overload would occur. An alternative precaution is to include a safety resistance in series with the meter which may be cut out if the deflection does not exceed a certain value.

Such a safety resistance may be worked out as follows:

Make up or purchase a resistance of such a value that if connected in series with the meter across the battery which is to be used (a 2 volt battery will suffice for normal purposes) the current is just equal to the full scale deflection on the meter. For example, a 30 milliamp meter used with a 2 volt battery would require a resistance of 66 ohms, which would be obtained by using three yards of 38 gauge Eureka wire. When taking any tests this resistance should be inserted in series with the resistance to be measured. If the deflection on the meter does not exceed *half* the full scale deflection, then the protective resistance may be cut out quite safely for the deflection will then not exceed the full scale value. From the current which is obtained and the knowledge of the voltage of the battery, the resistance can easily be determined.

A 2 volt battery and a meter reading 20 or 30 milliamps full-scale deflection can be used satisfactorily up to resistances of about 2,000 ohms, when the deflection will be 1 milliamp. If one requires to read higher values of resistance than this, a more sensitive meter must be used, or the voltage applied to the device under test must be increased. In testing a transformer, for example, one could with advantage increase the volts to 6 or 9. This would give a current of between 5 and 10 milliamps through the primary and between 1 and 2 milliamps for the secondary, which is sufficiently accurate for a check. Care must always be taken that the current which is permitted to flow through the circuit is not so large as to cause over-heating of the winding. For example, a current of 20 milliamps through the secondary of a transformer would give rise to serious overheating if it was allowed to endure for long, and would probably burn out the instrument altogether.

High Resistances

When we come to the measurement of high resistances exceeding 10,000 ohms and running into 1 or 2 megohms, the problem becomes more difficult. In the first place, a sensitive meter must be used, having a full scale deflection of 1 or 2 milliamps only, and capable of reading one-tenth of a milliamp (100 microamps) with fair accuracy. Then the voltage used must be considerably increased, and here it is permissible to use a dry (H.T.) battery, giving 100 volts or more. This

is because the current taken from the battery will be so small that no serious drop in voltage is likely to result.

Let us assume, for example, that we wish to measure a resistance of about 1 megohm. 100 volts connected across this resistance would only cause a current of one-tenth of a milliamp, which can just be measured on a meter of the type referred to. If one can measure accurately currents of 40 or 50 microamps, then one can read resistances, with a 100 volt battery, up to 2 megohms satisfactorily. With lower values of resistance, of course, the current increases rapidly. A resistance of 100,000 ohms would pass 1 milliamp, while a resistance of 10,000 ohms would pass 10 milliamps, which is in excess of the maximum scale reading of our instrument.

It is desirable to include a safety resistance in the meter in this case as in the previous example. The value of resistance must be worked out in just the same way as before, but one usually finds that the resistance is now of a very high value, and it is, therefore, desirable to use a suitable standard resistance which best meets the requirements. For example, if our meter gives a full scale deflection of 2 milliamps, a resistance of 50,000 ohms would serve admirably as a safety resistance if one proposed to use a battery of 100 volts or less. Then, as in the previous case, provided the deflection did not exceed half the full scale (1 milliamp in the case in point) one could with safety remove the protective resistance and so obtain the true resistance of the circuit under test.

Where one is in possession of an ohmmeter, of course, all these precautions do not have to be taken, for one merely connects the resistance under test across the terminals and measures the resistance according to the calibrations on the scale which read directly in ohms, without any further bother.

The most satisfactory method of measuring high resistances is by means of an insulation tester such as a Megger. These instruments contain a small, hand-driven generator developing a fairly high voltage (anything from 100 to 1,000 volts, according to the type). These instruments again give a direct reading of the resistance connected across the terminals, and have the advantage that they apply a high voltage which is sufficient to break down an imperfect insulation, whereas a relatively small voltage would not do this. Such apparatus,

however, is expensive, and is more in the nature of laboratory equipment.

H.F. CHOKES

The tests outlined cover the majority of cases likely to be encountered in ordinary practice. One does occasionally find it desirable to obtain some check on the performance of an H.F. choke. As was pointed out in the chapters on Tuning and High-Frequency tests, the H.F. choke can introduce various troubles if it is of inadequate inductance. A simple test which can easily be connected up and which gives a good idea of the capabilities of the choke is the following:

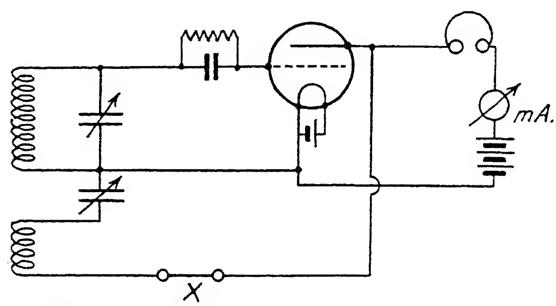

FIG. 82.—CIRCUIT FOR TESTING H.F. CHOKES.

The circuit is connected up as shown in Fig. 82. It will be seen to consist of a single-valve detector circuit using capacity-controlled reaction. Plug-in coils are used, and a series of pairs of coils must be chosen for the tuned winding and the reaction coil, such that the circuit can be made to oscillate comfortably with a relatively small value of reaction condenser over a waveband extending from say 200 to 2,000 metres. Having obtained the required data on this point, the reaction circuit is broken at the point marked *X* and the high-frequency choke is inserted. The circuit is now tuned slowly from the bottom to the top of the scale, changing the coils where necessary, endeavouring the whole of the time to make it oscillate. If the choke is satisfactory, it will not oscillate at all, since the choke acts as a complete barrier to the high-frequency current. At one point, usually between 1,500 to 2,000 metres, the circuit will suddenly commence to

oscillate, and will continue to do so thereafter without trouble. This is the upper limit of choking and is the point at which the choke ceases to be effective. With a good choke this point would not occur until over 2,000 metres, but in many so-called chokes oscillation sets in at as low as 1,000 metres.

Any subsidiary resonant points or "holes" as they are called will be shown up by this test, for the circuit will oscillate over a few degrees on the dial, if any such point is found. The presence of such a resonance means trouble, if the choke is used in a receiver, for there will be a strong tendency to self-oscillation at this wavelength. The test is not by any means quantitative, but it does give a fairly reliable indication of the properties of any particular choke.

VALVE TESTS

The obvious test to be made on a valve is that of taking its characteristics. This, of course, is a cumbersome business, but in some instances one does require to know something about the parameters of the valve. It will not be out of place, therefore, to give details of how this may be done. The circuit should be arranged as shown in Fig. 83. There is a voltmeter to read the anode voltage, a milliammeter to determine the anode current and a voltmeter to determine the grid voltage. The high tension voltage must be variable in steps, and the tappings on an ordinary H.T. battery will serve for this purpose. The grid voltage must also be variable in steps and for ordinary purposes it is sufficient to use the $1\frac{1}{2}$ volt tap on a grid bias battery. In special cases a potentiometer across the filament must also be resorted to, so that finer variations are possible, and this device has been shown in the figure.

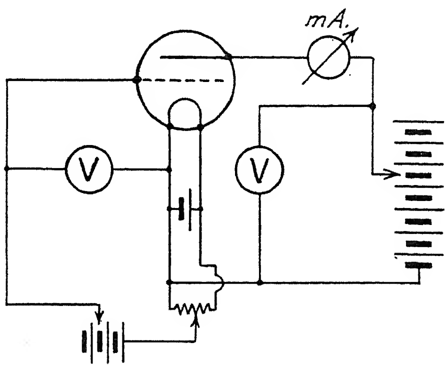

FIG. 83.—CIRCUIT FOR TAKING VALVE CHARACTERISTICS.

In order to determine the characteristics a normal anode voltage is usually used, and the grid bias is varied from zero to some negative value until the anode current has been reduced practically to zero. The test is then repeated for one or two other values of anode voltage. If a screened-grid valve is being used, the screen must be connected to the correct voltage during the test, and the same remark applies to pentode valves.

If other characteristics are required, these must be plotted by varying the required voltages. For example, with power valves, one often requires to know the variation of current with anode voltage at a fixed value of grid voltage. Any such characteristic may easily be taken with the apparatus shown.

Usually, however, it is sufficient to determine the internal resistance and amplification factor under working conditions. For this purpose the valve should be set up with its correct anode voltage and grid bias. First of all the anode voltage is increased to 10 volts above the normal value and the anode current noted. The anode voltage is then reduced to 10 volts below normal value, and the current again noted. This gives us the first parameter.

$$\text{Internal resistance} = \frac{\text{Change in anode voltage (20 = in this case)}}{\text{Change in anode current.}}$$

The anode voltage is now restored to its normal value, and the grid voltage is increased to $1\frac{1}{2}$ volts above normal, and the anode current noted. The grid voltage is now reduced $1\frac{1}{2}$ volts less than normal, and the anode current again noted. This gives us the second parameter.

$$\text{Mutual conductance} = \frac{\text{Change in anode current}}{\text{Change in grid voltage (3 in this case).}}$$

The amplification factor is obtained by multiplying these two factors together.

Where one is dealing with A.C. valves all measurements must, of course, be made relative to the cathode, while the heater is supplied separately with current either from a 4-volt transformer or a 4-volt battery as required. This requires the use of a special holder and a slight modification of the connections.

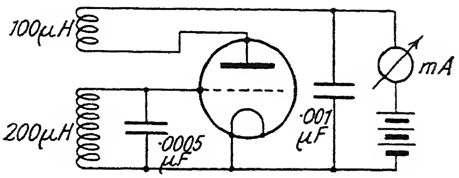

FIG. 84.—CIRCUIT FOR RAPID CHECKING OF EMISSION.

Where it is not required to make a definite check on the performance of a valve, but merely to find whether it is functioning satisfactorily, a much simpler form of test will suffice. It is sufficient, for example, to connect the valve in circuit with the grid connected to L.T. — and with a suitable anode voltage, say 50, to note whether any anode current is obtained. This is satisfactory for all except very high resistance valves where the anode current is so small as to render the reading difficult to observe. This, of course, can be overcome by the use of a specially sensitive meter, having a full scale of 2 milliamps only.

A form of test which is convenient for all valves is to use an oscillating circuit. Such an arrangement, as that shown in Fig. 84, is convenient. Here we have an oscillating arrangement with a tuned grid circuit and a reaction coil in the anode circuit, which also contains a milliammeter. An H.T. voltage of about 60 is all that is necessary, and if the valve is in order the circuit will oscillate strongly, causing a large deflection

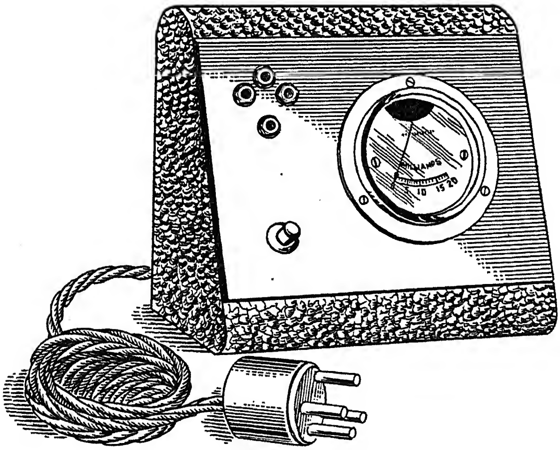

FIG. 85.—BULGIN VALVE TESTER.

of perhaps, 10 or 20 milliamps in the anode circuit. If the valve is not satisfactory, no appreciable current will be obtained, so that one immediately obtains an indication as to whether the valve is not only intact, but in good working order, for if it will oscillate it will usually perform its other functions equally satisfactorily.

A convenient little valve tester made up on this principle is marketed by Messrs. A. F. Bulgin & Co., and is illustrated in Fig. 85. The valve is inserted in the holder and the button depressed. If the valve is in order a large deflection is obtained on the meter, whereas otherwise no deflection results. The tester is equally satisfactory for high- or low-resistance valves.

LABORATORY TESTS

There are one or two tests on components which cannot be applied by means of ordinary simple apparatus. They involve equipment usually only found in a laboratory, but they are of sufficient importance to merit some brief reference in order to render this work complete.

Capacity Measurement

First of all we have the inductance and capacity bridges. Much has been written on these and it will suffice to show a very simple form of each. Fig. 86 shows what is known as Wien Bridge. It will be seen to consist essentially of a Wheatstone Bridge with capacities in each arm instead of resistances. If the two top capacities are equal, then we have an equal ratio bridge, and if the variable standard capacity in the bottom left hand arm is made equal to the unknown capacity in the bottom right hand arm, we obtain a condition of balance.

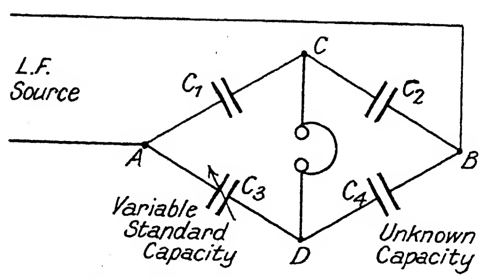

FIG. 86.—WIEN BRIDGE FOR CAPACITY MEASUREMENT.

Voltage is applied across the points *A* and *B* from a suitable low-frequency source such as an L.F. oscillator or some

similar device. The current produced by this voltage divides, part flowing through the top half of the bridge, and the other part through the bottom half. At the point C the voltage drop will be exactly one-half of the total voltage, since the two capacities, C_1 and C_2 are equal. The same remark applies at the point D and, therefore, the voltage at these two points is exactly the same. Consequently a pair of telephones connected across these points would carry no current whatever. This condition only applies when the bridge is balanced (so that the standard variable capacity equals the unknown capacity) and on either side of this point a certain current will flow through the telephones. In operation, therefore, the standard is adjusted until a silent point is obtained, when the capacity of the standard is equal to that of the unknown condenser.

By making the top left hand arm some definite ratio of the top right hand arm, we obtain our balance in the same way. For example, if the unknown capacity is larger than the maximum capacity of the standard, we should simply make the right hand ratio arm two or three times the capacity of the left hand arm. Balance will then be obtained when the standard capacity was one-half (or one-third) of the unknown capacity, and this would occur within its range. An exactly similar state of affairs applies if the standard capacity is large compared to the unknown capacity so that the reading occurs at the bottom end of the scale where it is difficult to determine accurately. We should use a multiplying ratio so that the reading will be transferred to a more open part of the scale.

INDUCTANCE MEASUREMENT

A similar bridge for inductances is shown in Fig. 87. Here the top two arms are made of resistances, having a value in the neighbourhood of 100 ohms. A standard variable inductance is included in the left hand bottom arm, this usually being of the variometer type, while in the bottom right hand arm is the unknown inductance. In this case, however, we not only have to balance the inductances, but also the resistances of the circuits, and therefore, a variable resistance is shown included in the circuit. We cannot say off-hand in which arm this resistance must be placed. We may find that

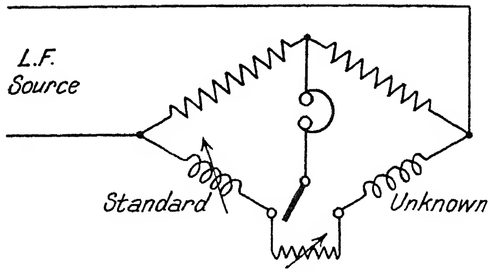

FIG. 87.—INDUCTANCE BRIDGE.

the resistance of the standard is more or less than that of the unknown inductance, and accordingly we must place the extra resistance in either the right hand or the left hand arm respectively in order to balance for resistance. This is done by throwing the switch in to one of these two possible positions.

In practice one has to balance this bridge by adjusting both the inductance and the resistance simultaneously, obtaining a minimum on one, then reducing the strength of this minimum on the other. Going from one to the other in this way a silent point is ultimately obtained, and this gives the inductance of the unknown coil. As before, ratios may be used where the unknown inductance is greater or less than the standard.

These methods for measuring capacity and inductance are at once more accurate and more convenient than the wavemeter method, but a little difficulty is likely to be experienced due to self-capacity and earth capacity effects. Further information should be obtained from some of the various works on bridge measurement.[1]

The measurement of large capacities is one which is not called for often, and no reference need be made to it here. Information on the subject will be found in the work already referred to.

IRON-CORED INDUCTANCES

Measurement of large inductances, however, particularly iron-cored inductances, is a matter of considerable interest in radio work. Here the measurement is one of a little difficulty, for one has to take account of the presence of steady current flowing through the winding. The inductance of an iron-cored coil, whether a transformer primary or choke,

[1]Notably W. H. Nottage.—*Calculation and Measurement of Inductance and Capacity.*

depends upon the permeability of the iron, which is not a constant property, but varies according to the state of magnetisation of the iron. If we pass a steady current through the winding (such as the anode current flowing through a transformer primary) we introduce a steady magnetisation into the core, and the fluctuating current passing through it causes variations about this steady state.

The effective permeability of the iron, which is what determines the inductance under practical conditions, falls off steadily and somewhat rapidly as we increase the steady magnetisation of the iron, so that the larger the steady current the less the inductance of the coil. This effect is known as "saturation." It may be avoided by the use of specially constructed iron circuits, employing a small air gap (constant-inductances chokes), but otherwise the effect is nearly always present.

A further effect is that the inductance of an iron-cored coil varies considerably with the alternating component of the current flowing through it. If one measures the inductance with an alternating current of 1 milliampere, and then again with 5 milliamperes, the inductance will be found to be, perhaps, twice as great as in the latter case. We have two essentials, therefore, to comply with in making our measurement.

1. The steady current flowing through the winding must be commensurate with the value to be used in practice.

2. The alternating component of the current must also be of the correct order.

In practice a value of 0·25 milliamps A.C. will be found sufficient for transformers and high-inductance chokes, as the difference between the inductance under such conditions and that with small currents flowing is negligible. With chokes intended for smoothing eliminator circuits, a value of 1 milliampere or more should be used.

A circuit which can be employed in making these measurements is that shown in Fig. 88. In series with the inductance to be measured is a small resistance. This must be of such a value that it is negligible in comparison with the impedance of the inductance to be measured. A value of 50 to 100 ohms is usually sufficient. Across this resistance is connected a valve voltmeter with one stage of resistance-coupled ampli-

fication preceding it. This is in order to obtain the requisite sensitivity, as the customary valve voltmeter will not give any indication, unless this step is resorted to. The circuit is completed with the switch having two positions. In the first the circuit contains an A.C. milliammeter capable of reading 1 to $1\frac{1}{2}$ milliamperes full-scale deflection. In the second a D.C. milliammeter and battery is brought into use, the sizes depending on the polarising current to be taken by the choke.

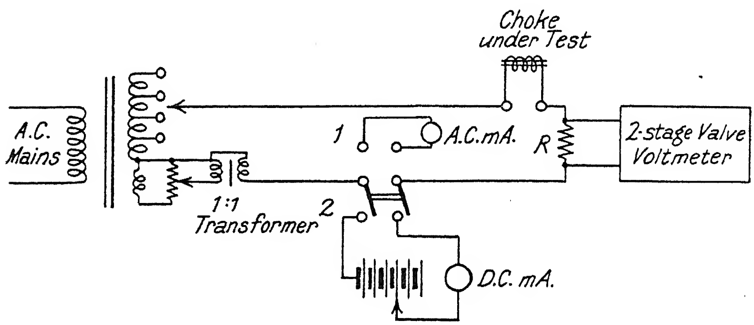

FIG. 88.—CIRCUIT FOR TESTING IRON-CORED INDUCTANCE.

A variable transformer is employed connecting the circuit to the mains supply if it is convenient, and of reasonably good wave form. Alternatively a local oscillator must be employed, suitably coupled to the circuit, so that a variable voltage can be induced therein. The voltage is increased (with the switch in position 1) until the required current (0·25 or 1·0 milliampere as the case may be) is flowing in the circuit. The voltage drop on the resistance R will cause a deflection on the valve voltmeter, and this deflection must be noted. Throughout the measurements we then know this deflection on the valve voltmeter corresponds to a definite value of A.C.

The switch is now thrown into position 2 which brings in the battery and a D.C. ammeter. This is now adjusted until the requisite direct current passes through the choke. This will have no effect upon the valve voltmeter, which does not take any account of D.C. voltages applied across its terminals. The A.C. voltage applied to the circuit is now varied until the reading on the valve voltmeter is the same as before, indicating that the required value of alternating current is

flowing. The voltage across the choke is measured with a suitable A.C. voltmeter, and by dividing this voltage by the predetermined value of alternating current to which the circuit has been adjusted, we are able to determine the impedance of the choke.

In nearly all cases this impedance may be taken to be purely reactive since the resistance is usually negligible. This is particularly the case if one is using a relatively high frequency for the measurements. Such being the case, one may assume that:

$$\text{Inductance} = \frac{\text{A.C. voltage across choke}}{6{\cdot}28 \times \text{frequency} \times \text{A.C. amperes.}}$$

The method is one which gives good practical results with an accuracy quite sufficient for normal purposes.

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